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Supplementary Guidelines for Lead Implementation Plans

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Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

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16. ABSTRACT

This guideline presents information on the development of implementation plans for lead that are not contained in EPA's regulations for preparation, adoption, and submission of implementation plans, found in Part 51 of Title 40 of the Code of Federal Regulations. In several cases, the guidance presented herein is referenced in those regulations; EPA will use this guidance in determining the acceptability of a plan.

The guideline covers the following topics: general implementation plan development, reporting requirements, analysis and control strategy development, siting of urban area ambient air quality monitors for lead, new source review, and the determination of the lead point source definition. In addition, appendices cover the following topics: procedures for determining inorganic and organic lead emissions from stationary sources, projection of automotive lead emissions, deposition of particles and gases, and rollback modeling.

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Supplementary Guidelines for Lead Implementation Plans

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

August 1978

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OAQPS GUIDELINE SERIES

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PREFACE

This guideline appeared in draft form in November of 1977 and was referred to in the preamble to the proposed regulations on lead implementation plans, which appeared in the Federal Register of December 14, 1977, (42 FR 63087). This final edition reflects a number of changes from the draft version. The significant revisions are as follows:

--Revision of section 3.2 concerning HATREMS.

--Revision of section 4.3 on projecting automotive lead emissions to correct errors in the units in the equations and provide values for several expressions.

--Inclusion of a new section (4.4) on air quality modeling.

--Revision of Chapter 5 on siting of urban area ambient air quality monitors for lead to reflect a number of comments.

--Deletion of the draft Chapter 7, which was a brief description of the emission sampling technique.

--Revision of the inorganic lead testing method that appeared in Appendix A, and the inclusion of a test method for alkyl lead, which appears as the new Appendix B.

--Addition to the material on deposition of particles and gases in the new appendix D (Appendix C in the draft) with more recent, more representative material; this new material appears as Appendix E.

--Inclusion of a paper that describes the modified rollback model, required as a minimum in several of the analyses in the State implementation plans; this appears as Appendix G.

There are also a number of changes that were made to reflect the revision of the national ambient air quality standard from a monthly average to a quarterly average.

ACKNOWLEDGEMENTS

This guideline was prepared under the general editorship of John Silvasi and Joseph Sableski of the Plans Guidelines Section, Standards Implementation Branch, Control Programs Development Division. CPDD gratefully appreciates the following contributions:

Chapter 3--Reporting Requirements	Jacob Summers MDAD
Chapter 5--Ambient Lead Monitoring	Alan Hoffman MDAD
Chapter 7--Determination of Lead Point Source Definition	James Dicke MDAD
Appendix A--Procedures for Determining Inorganic Lead Emissions from Stationary Sources	Bill Mitchell, Rodney Midgett EMSL
Appendix B--Procedure for Determining Alkyl Lead Emissions from Alkyl Lead Manufacturing Plants	Bill Mitchell, Rodney Midgett EMSL
Appendix C--Projecting Automotive Lead Emissions for Roadway Configurations	James Wilson MDAD

CPDD gratefully acknowledges the permission granted by Pergamon Press and Thomas W. Horst to reproduce the article, "A Surface Depletion Model for Deposition from a Gaussian Plume," which appeared in Atmospheric Environment in 1977.

In addition, CPDD wishes to thank those who offered comments and suggestions on the draft of this guideline.

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1.0 INTRODUCTION

This guideline presents information on the development of implementation plans for lead that are not contained in EPA's regulations for preparation, adoption, and submission of implementation plans, found in Part 51 of Title 40 of the Code of Federal Regulations. In several cases, the guidance presented herein is referenced in those regulations; EPA will use this guidance in determining the acceptability of a plan.

A detailed summary of the background surrounding the development of the regulations and the guidelines appears in the preambles to both the proposal (Federal Register of December 14, 1977 (42 FR 63087)), and the final version of the regulations pertaining to lead implementation plans.

2.0 GENERAL SIP DEVELOPMENT GUIDELINES

The discussion below follows the outline of those portions of the 40 CFR 51 regulations, "Requirements for Preparation, Adoption, and Submittal of Implementation Plans," that were not revised to account for the lead standard. These requirements are still applicable to the lead SIPs as appropriate. Items of a peripheral nature, such as "Definitions," are not discussed here. The State should consult the regulations themselves, rather than this discussion, for the detailed requirements.

2.1 SUBPART A--GENERAL PROVISIONS

--§ 51.3 Classification of regions--This section will not apply to lead SIPs.

--§ 51.4 Public hearings--Before the State submits the plan, a compliance schedule, or a plan revision to EPA, it must hold a public hearing on the plan, schedule or revision. The State must also give proper public notice for the hearing at least 30 days prior to the hearing. Although this section specifies formal requirements for the notice and holding of public hearings, a State can obtain EPA approval to use alternative procedures that EPA deems adequate.

--§ 51.5 Submission of plans; preliminary review of plans--The State must submit at least five copies of the plan to the appropriate Regional Office within nine months after EPA promulgation of a primary or secondary standard. The State can obtain from EPA an extension of

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18 months to submit a plan to implement the secondary standard; this provision is not applicable to lead plans, however, since the secondary standard and primary standard are identical. Plans for different AQCRs within a State can be submitted as a single document or as separate documents.

A State can submit to EPA a plan or portions thereof for preliminary review before it is due.

--§ 51.6 Revisions--EPA may ask a State to revise its plan for three reasons:

(a) Revisions of a national standard.

(b) The availability of improved or more expeditious methods of attaining the national standards.

(c) A finding by EPA that the plan is substantially inadequate to attain or maintain the national standard which it implements.

After notification that a plan needs revision, the State has 60 days or any longer period specified by EPA to submit the revision.

--§ 51.7 Reports--The State must report air quality data to EPA on a quarterly basis and must submit the data in a specified format for conversion to machine-readable format.

The State must also report emissions from point sources whenever there is a change in emissions, such as a source coming into compliance, a new source beginning operation, and a source ceasing operation. The State must also submit the emissions data in a specified format for conversion to machine-readable format. In addition, States must report on progress in plan enforcement and on any substantive revisions the State makes in the plan other than to rules and regulations. EPA intends to revise these requirements shortly; the revisions will cover all the pollutants for which implementation plans are needed, including lead.

2.2 SUBPART B--PLAN CONTENT AND REQUIREMENTS

--§ 51.10 General requirements--A plan must provide for attainment of national primary air quality standards within three years after the date of EPA approval of the plan, although the State can obtain a two-year extension upon EPA approval of application. A plan must provide for attainment of national secondary air quality standards within a reasonable time after the date of EPA approval of the plan; this provision is inapplicable to the lead plans because the primary and secondary lead air quality standards are identical. Also, the plan for one AQCR must provide that emissions from the AQCR do not interfere with attainment and maintenance of a national standard in another AQCR. In addition, the plan must provide for public availability of emission data from all sources, correlated with allowable emissions.

--§ 51.11 Legal authority--The plan must show that the State has the legal authority to--

--adopt emission limitations;

--enforce laws, regulations, and standards, and seek injunctive relief;

--abate emissions during an emergency episode;

--prevent construction or modification of facilities that may result in a violation of a national air quality standard;

--obtain information necessary to determine compliance;

--require source owners to install emission monitoring devices; and

--make emission data available to the public.

If the plan contains measures for transportation and land use controls (other than new and modified source review), the plan does not have to demonstrate that authority for such measures exists at the time of plan submission. In such cases, however, the plan must contain a schedule for obtaining the legal authority.

A State may delegate authority and responsibility to a substate entity for carrying out a plan or portion thereof if the plan demonstrates that the substate entity has the legal authority for carrying out its responsibility and that the State is not relieved of the responsibility for carrying out the plan or portion thereof if the substate entity fails in its reponsibility. (§ 51.55 of Subpart D, which pertains to plans in AQMAs and like areas, provides an exception to this requirement.)

--§ 51.12 Control strategy: General--This section prescribes some general requirements for developing and evaluating the control strategy, which is the heart of the implementation plan. The plan must demonstrate that the control strategy is adequate to attain the standard within the appropriate period and maintain it thereafter. (Subpart D of the regulations, discussed below, specifies additional maintenance requirements for some areas.)

--§ 51.13 Control strategy: Sulfur oxides and particulate matter.

--§ 51.14 Control strategy: Carbon monoxide, hydrocarbons, photochemical oxidants, and nitrogen dioxide.

These two sections set forth requirements specific to the subject pollutants and do not apply to the lead implementation plans. The control strategy requirements for the lead implementation plan are found in a newly-created Subpart E.

The process of developing and evaluating a control strategy for attainment of the national standard entails the following:

--Development of an emission and air quality data base.

--Determination of whether the air quality standard is being violated.

--Development of alternative control strategies.

--Evaluation of the control strategies by accounting for emission reductions and modeling air quality concentrations.

--Choice of an appropriate strategy.

Detailed guidance for performing these tasks appears in EPA's Air Quality Analysis Workshop, Volume 1 - Manual.[1]

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[1] Cirillo, R.R., et al., Air Quality Analysis Workshop, Volume 1 - Manual. Prepared for the Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. November 1975.

--§ 51.15 Compliance schedules--The plan must contain legally enforceable compliance schedules that set forth the dates by which all sources must be in compliance with any applicable portion of the plan. Schedules extending over a period of more than one year from the date of adoption must provide for legally enforceable increments of progress toward compliance. All schedules must provide for compliance by the statutory attainment date or the end of the period covered by an extension to the attainment date. Revisions to compliance schedules constitute revisions to the implementation plan; enforcement orders that extend beyond the date for attainment of the national standard must be issued in accordance with the requirements of Section 113(d) of the Clean Air Act.

--§ 51.16 Prevention of air pollution emergency episodes--As discussed in section 3.5 of the preamble to the proposed regulation, this section will not apply to lead implementation plans.

--§ 51.17 Air quality surveillance--These regulations pertain to pollutants other than lead and therefore do not apply to the lead implementation plans. The requirements for lead air quality surveillance appear in a newly-created § 51.17b.

--§ 51.17a Air quality monitoring methods--This section prescribes procedures for obtaining approval to use nonconforming analyzers (i.e., those analyzers that do not use the reference or equivalent methods), methods with nonconforming ranges, and methods that have been modified by users.

--§ 51.18 Review of new sources and modifications--The plan must provide legally enforceable procedures to enable the State to determine whether the construction or modification of a facility will result in violations of a portion of the control strategy or will interfere with attainment or maintenance of a national standard. The State must also have the ability and procedures to prevent construction or modification of facilities that will result in control strategy violations or interfere with a national standard. Before approving or disapproving requests to construct affected facilities, the State must provide opportunity for public notice of and comment on the action.

EPA intends to revise these requirements shortly; the revisions will cover all pollutants for which implementation plans are needed, including lead.

--§ 51.19 Source surveillance--The plan must provide for monitoring the status of compliance with any rules and regulations which constitute the control strategy. As a minimum, the plan must provide:

--Procedures for requiring owners or operators of sources to maintain records of emissions and report periodically to the State;

--Periodic testing and inspection of sources;

--A system of detection of violations of rules and regulations through enforcement of a visible emission limitation and for investigating complaints (the provision concerning visible emission limitations is inapplicable to the lead plan);

--Procedures for obtaining and maintaining data on emissions reductions achieved through transportation control measures; and

--Procedures to require sources to install and use emission monitoring devices (this provision is also inapplicable to the lead plan).

--§ 51.20 Resources--The plan must provide a description of the resources available to the State and local agencies at the time of plan submission and of any additional resources needed to carry out the plan during the five-year period following its submission.

--§ 51.21 Intergovernmental cooperation--The plan must provide assurances for the State to submit to other States air quality and emission data. Also, the plan must identify local agencies that will participate in implementing the plan and their responsibilities.

--§ 51.22 Rules and regulations--The State must adopt all rules and regulations necessary for attainment and maintenance of the national standard. The plan must contain copies of all such rules and regulations.

2.3 SUBPART C--EXTENSIONS.

--§ 51.30 Request for two-year extension--The Governor of a State may, at the time he submits a plan to implement a primary standard, request EPA to extend the 3-year period for attainment of the primary standard for a period not exceeding two years. To obtain the extension, the State must demonstrate a number of items, particularly that the necessary technology or alternatives will not be available soon enough to permit full implementation of the control strategy within three years.

--§ 51.31 Request for 18-month extension--Upon request of a State, EPA may extend, for a period not exceeding 18 months, the deadline for submission of a plan to implement a secondary air quality standard. As discussed above, this provision is inapplicable to the lead plans, because the primary and secondary ambient lead standards are identical.

--§ 51.32 Request for one-year postponement--The Clean Air Act Amendments of 1977 have rendered this section inapplicable; EPA will amend Part 51 to reflect this.

--§ 51.33 Hearings and appeals relating to request for one year postponement--This section prescribes the procedures relating to a request for a one year postponement under § 51.32. The Clean Air Act Amendments of 1977 have rendered this section inapplicable; EPA will amend Part 51 to reflect this.

--§ 51.34 Variances. This section requires States to submit variances to regulations as revisions to the plan under § 51.6.

2.4 SUBPART D--MAINTENANCE OF NATIONAL STANDARDS

This subpart pertains to the detailed analysis to determine whether a certain area will maintain a national air quality standard and to the plan to maintain the standard. EPA must select the areas to which the regulations of this subpart apply, and so the regulations do not apply to all areas.

The subpart consists of sections 51.41 through 51.63 inclusive. Topics of the sections concerning the analysis are submittal date, analysis period, guidelines, projection and allocation of emissions, projection of air quality concentrations, description of data sources, data bases, description of techniques, accuracy of calculations, and submittal of calculations. Topics of the sections concerning the plan are demonstration of adequacy, strategies, legal authority, intergovernmental cooperation, surveillance, resources, and submittal. Two other sections cover both the analysis and the plan and concern data availability and the use of alternative procedures.

2.5 FORTHCOMING REQUIREMENTS

In addition to the above mentioned regulations, EPA will shortly publish additional requirements that account for the Clean Air Act Amendments of 1977. These requirements will appeare either as regulations or policy guidance. The new requirements will cover the following topics:

--Provisions for review of new sources in nonattainment areas (this will not apply to lead plans).

--Additional transportation-related provisions.

--Accounting for stack heights.

--Assessing adequacy of plan in relation to long-term fuel supplies.

--Prevention of significant deterioration.

--Permit requirements.

--Indirect source review.

--Delegation of authority to local governments.

--Interstate pollution abatement.

--Consultation with governmental entities at the local and Federal level.

--Planning procedures to allow local governments more authority in developing and implementing plans.

--Noncompliance penalties.

--Permit fees.

--Composition of State air pollution boards.

--Provisions prohibiting loss of pay of employees at facilities that use supplemental control systems.

--Provisions for public notification of dangers of air pollution.

--Protection of visibility in certain areas.

--Emergency episode reporting.

--Energy or economic emergency authority.

--Suspension of transportation control measures.

--Measures to prevent economic disruption or unemployment.

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3.0 REPORTING REQUIREMENTS

3.1 AIR QUALITY DATA REPORTING

The quarterly air quality reporting requirements specified in 40 CFR 51.7(a) will apply to lead as well as the other criteria pollutants. The air quality data for lead will be stored in the Storage and Retrieval of Aerometric Data (SAROAD) System and utilized by EPA, States, and private individuals.

3.1.1 SAROAD System

The SAROAD System includes several data files which include the site file, the parameter-method file, geographical files, raw data files, and the summary file as well as the software necessary to update these files and generate reports from the data.

The site file contains a listing of all sites reporting data and includes a description of the physical characteristics of the site. Each site is assigned a unique code and this code must be attached to data to identify the sampling site. Only data with a valid site code will be accepted on the data bank.

The parameter-method file contains an entry for each valid combination of sampling and analysis method for each pollutant. Only data with a valid entry will be accepted on the data bank. The code '92' has been assigned for lead data collected by Hi-Vol and analyzed by atomic absorption. Additional codes may be requested through the Regional Offices.

The geographic files contain the specific SAROAD codes and the corresponding names and are utilized to print location names on standard reports.

The raw data files contain 80-90 million individual data values for the time period of 1957-present as collected and reported by EPA, State, and local control agencies. These data are available upon request in standard raw data listings and are utilized by programs to generate summary statistics.

The summary file contains quarterly and annual summary statistics which include frequency distributions, arithmetic and geometric means and standard deviations, first and second maximums, violation counts, etc. These summary statistics are available in standard reports.

3.1.2 Reporting Formats

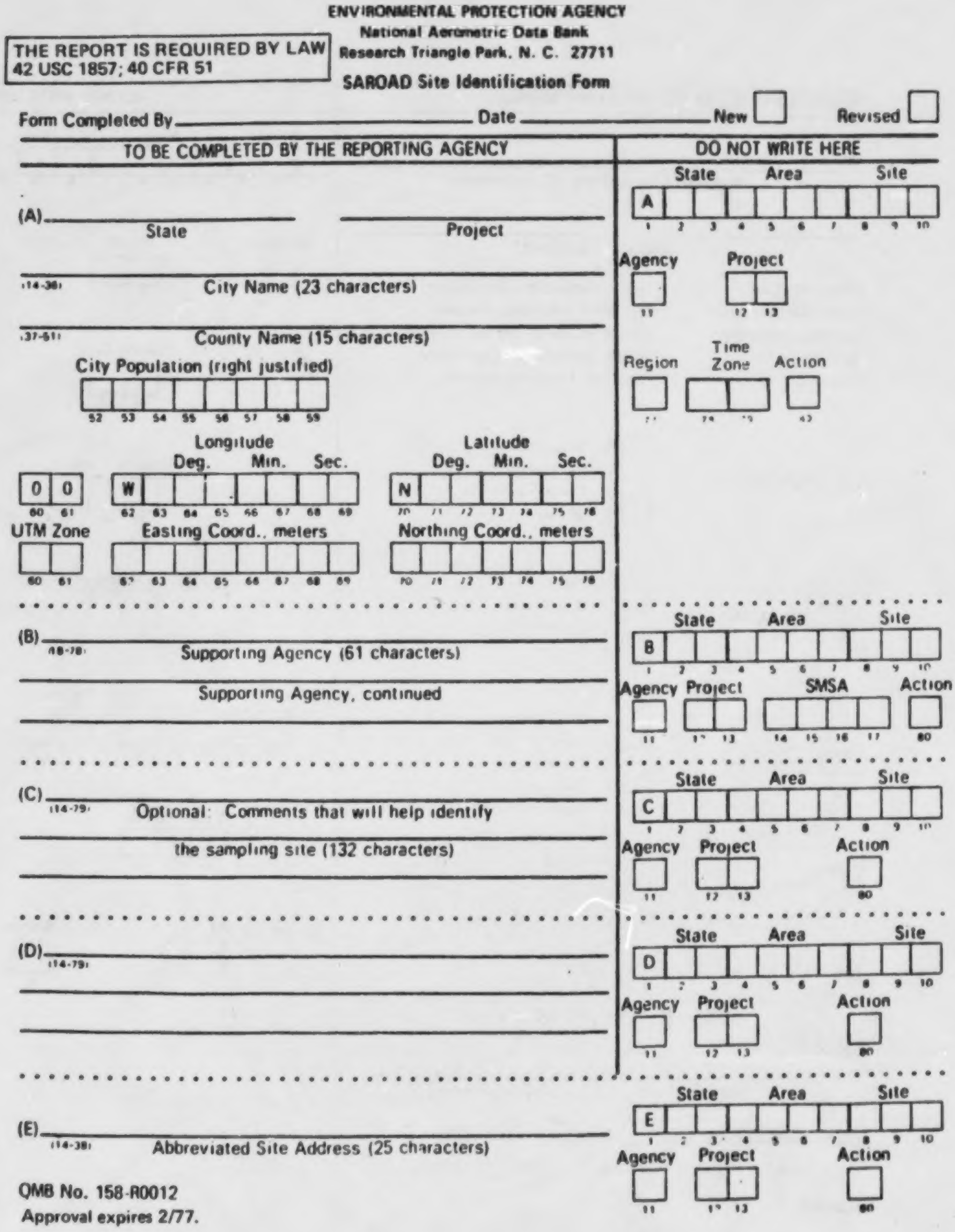
The standardized input formats which will be utilized to report lead data include: Figure 3.1-1 SAROAD Site Identification Form, Figure 3.1-2 SAROAD Daily Data Form, and Figure 3.1-3 SAROAD Composite Data Form.

The Site Identification Form is utilized to register a new site or change information for an existing site. The coding instructions are given in Section 3.4.1 of AEROS User's Manual.[1]

The Daily Data Form is utilized to report air quality concentrations for lead as determined from individual 24-hour integrated samples. The coding instructions are given in Section 3.4.3 of AEROS User's Manual.[1]

The Composite Data Form is utilized to report data values which are composites of individual 24-hour integrated samples. For lead, these composites could be done on a calendar month to reduce the resources required to analyze individual samples. The coding instructions are given in Section 3.4.4 of AEROS User's Manual.[1]

Figure 3.1-1



ENVIRONMENTAL PROTECTION AGENCY
National Aerometric Data Bank
Research Triangle Park, N. C. 27711
SAROAD Site Identification Form

THE REPORT IS REQUIRED BY LAW
42 USC 1857; 40 CFR 51

Form Completed By ______________________ Date ______________ New ☐ Revised ☐

TO BE COMPLETED BY THE REPORTING AGENCY

(A) ______________ State ______________ Project

(14-36) ______________ City Name (23 characters)

(37-51) ______________ County Name (15 characters)

City Population (right justified) ☐☐☐☐☐☐☐☐ (52–59)

	Longitude				Latitude			
		Deg.	Min.	Sec.		Deg.	Min.	Sec.
0 0 (60 61)	W (62)	63 64 65	66 67	68 69	N (70)	71 72	73 74	75 76

UTM Zone	Easting Coord., meters	Northing Coord., meters
☐☐ (60 61)	☐☐☐☐☐☐☐☐ (62–69)	☐☐☐☐☐☐☐ (70–76)

(B) (18-78) ______________ Supporting Agency (61 characters)

______________ Supporting Agency, continued

(C) (14-79) ______________ Optional: Comments that will help identify

______________ the sampling site (132 characters)

(D) (14-79) ______________

(E) (14-38) ______________ Abbreviated Site Address (25 characters)

OMB No. 158-R0012
Approval expires 2/77.

DO NOT WRITE HERE

	State		Area				Site		
A (1)	2	3	4	5	6	7	8	9	10

Agency ☐ (11) Project ☐☐ (12 13)

Region ☐ Time Zone ☐☐ Action ☐

	State		Area				Site		
B (1)	2	3	4	5	6	7	8	9	10

Agency ☐ (11) Project ☐☐ (12 13) SMSA ☐☐☐☐ (14 15 16 17) Action ☐ (80)

	State		Area				Site		
C (1)	2	3	4	5	6	7	8	9	10

Agency ☐ (11) Project ☐☐ (12 13) Action ☐ (80)

	State		Area				Site		
D (1)	2	3	4	5	6	7	8	9	10

Agency ☐ (11) Project ☐☐ (12 13) Action ☐ (80)

	State		Area				Site		
E (1)	2	3	4	5	6	7	8	9	10

Agency ☐ (11) Project ☐☐ (12 13) Action ☐ (80)

Figure 3.1-1 (cont'd)

SAROAD Site Identification Form (continued)

TO BE COMPLETED BY THE REPORTING AGENCY

(F)____
(14 - 54) Sampling Site Address (41 characters)

____
Address, continued

Check the ONE major category that best describes the location of the sampling site.

Next, check the subcategory that best describes the dominating influence on the sampler within approximately a 1-mile radius of the sampling site

1. ☐ CENTER CITY
   - ☐ 1. Industrial
   - ☐ 2. Residential
   - ☐ 3. Commercial
   - ☐ 4. Mobile

2. ☐ SUBURBAN
   - ☐ 1. Industrial
   - ☐ 2 Residential
   - ☐ 3. Commercial
   - ☐ 4 Mobile

3. ☐ RURAL
   - ☐ 1. Near urban
   - ☐ 2. Agricultural
   - ☐ 3. Commercial
   - ☐ 4. Industrial
   - ☐ 5. None of the above

4. ☐ REMOTE

Specify units ________________________________
Elevation of sampler above ground

Specify units ________________________________
Elevation of sampler above mean sea level

Circle pertinent time zone EASTERN CENTRAL MOUNTAIN PACIFIC YUKON ALASKA BERING HAWAII

DO NOT WRITE HERE

State			Area				Site		
F	☐	☐	☐	☐	☐	☐	☐	☐	☐
1	2	3	4	5	6	7	8	9	10

Agency ☐ 11

Project ☐☐ 12 13

Station Type ☐☐ 55 56

County Code ☐☐☐☐ 57 58 59 60

AOCR Number ☐☐☐ 61 62 63

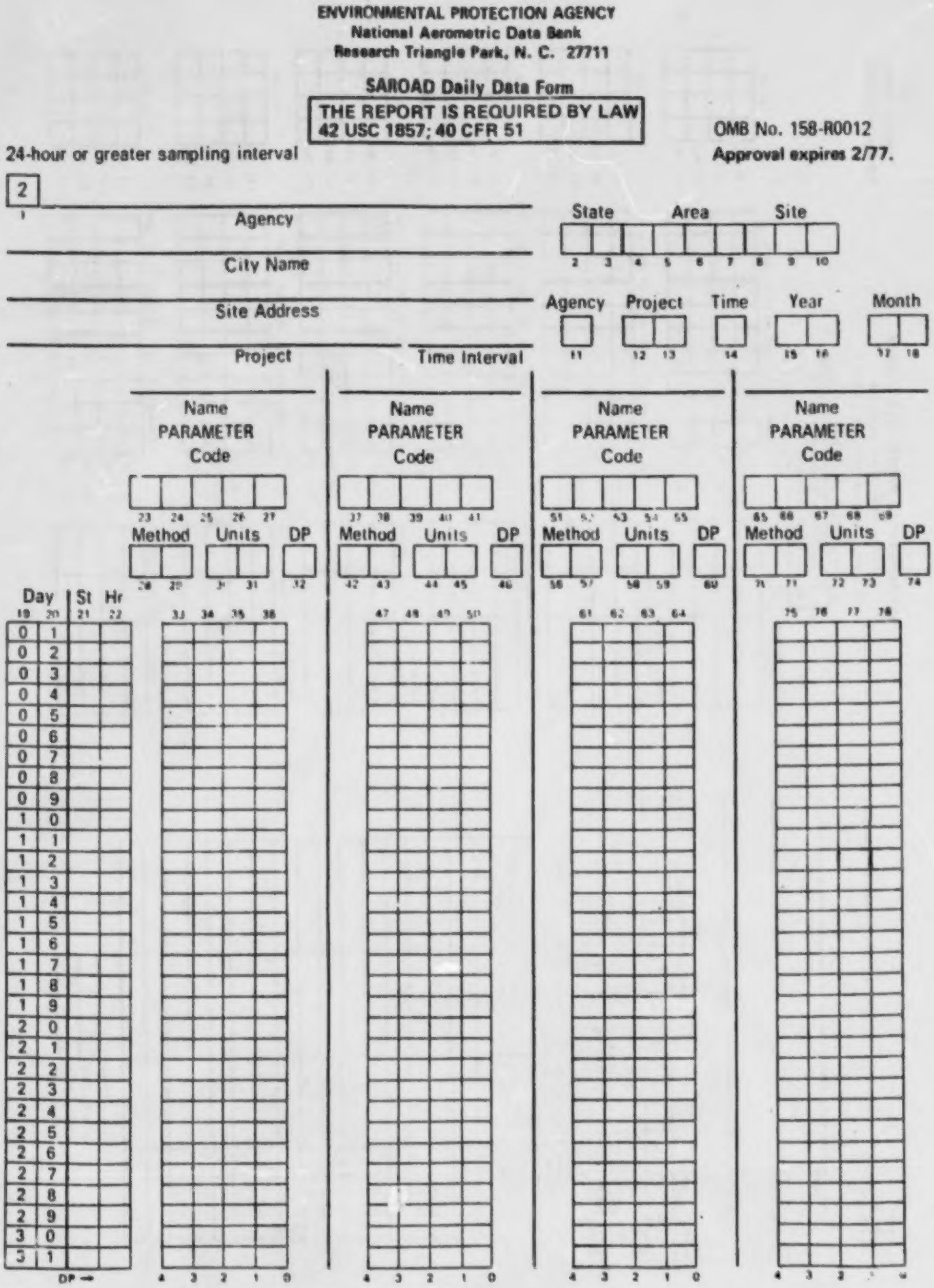
AOCR Population ☐☐☐☐☐☐☐☐ 64 65 66 67 68 69 70 71

Elevation/Gr ☐☐☐ 72 73 74

Elevation/MSL ☐☐☐☐ 75 76 77 78

Action ☐ 80

Figure 3.1-2



ENVIRONMENTAL PROTECTION AGENCY
National Aerometric Data Bank
Research Triangle Park, N. C. 27711

SAROAD Daily Data Form

THE REPORT IS REQUIRED BY LAW
42 USC 1857; 40 CFR 51

OMB No. 158-R0012
Approval expires 2/77.

24-hour or greater sampling interval

2 (1)

Agency ______

City Name ______

Site Address ______

Project ______ Time Interval ______

State ☐☐ Area ☐☐☐☐ Site ☐☐☐ (2 3 4 5 6 7 8 9 10)

Agency ☐ (11) Project ☐☐ (12 13) Time ☐ (14) Year ☐☐ (15 16) Month ☐☐ (17 18)

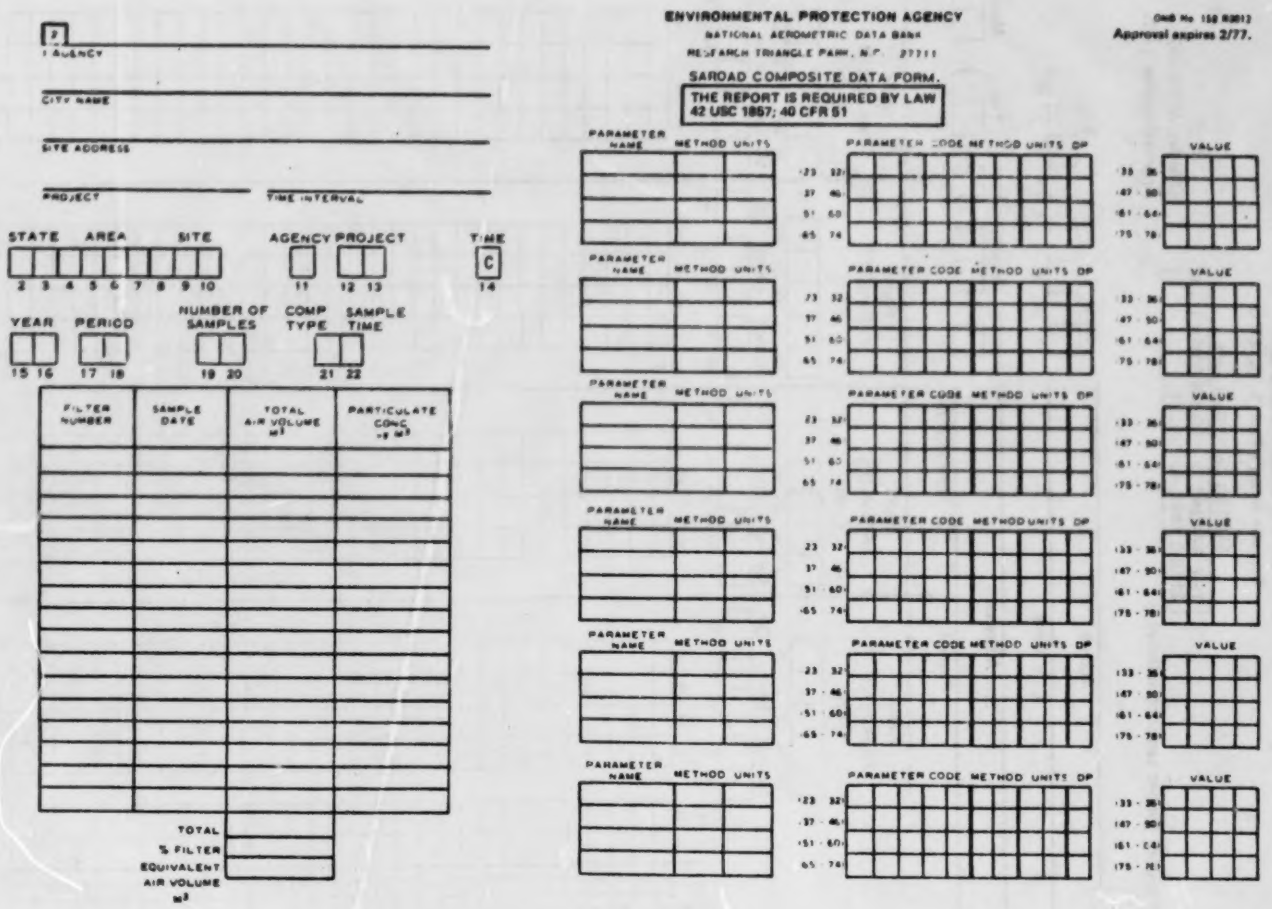
Name PARAMETER Code	Method	Units	DP	Data columns
23 24 25 26 27	28 29	30 31	32	33 34 35 36
37 38 39 40 41	42 43	44 45	46	47 48 49 50
51 52 53 54 55	56 57	58 59	60	61 62 63 64
65 66 67 68 69	70 71	72 73	74	75 76 77 78

Day (19 20)	St (21)	Hr (22)
0 1		
0 2		
0 3		
0 4		
0 5		
0 6		
0 7		
0 8		
0 9		
1 0		
1 1		
1 2		
1 3		
1 4		
1 5		
1 6		
1 7		
1 8		
1 9		
2 0		
2 1		
2 2		
2 3		
2 4		
2 5		
2 6		
2 7		
2 8		
2 9		
3 0		
3 1		

DP → 4 3 2 1 0   4 3 2 1 0   4 3 2 1 0   4 3 2 1 0

Reproduced from
best available copy.

Figure 3.1-3



ENVIRONMENTAL PROTECTION AGENCY
NATIONAL AEROMETRIC DATA BANK
RESEARCH TRIANGLE PARK, N.C. 27711

SAROAD COMPOSITE DATA FORM.

THE REPORT IS REQUIRED BY LAW
42 USC 1857; 40 CFR 51

OMB No. 158 R0012
Approval expires 2/77.

☐ 2
1 AGENCY ______________________

CITY NAME ______________________

SITE ADDRESS ______________________

PROJECT ____________ TIME INTERVAL ____________

STATE	AREA	SITE	AGENCY	PROJECT	TIME
2 3	4 5 6 7	8 9 10	11	12 13	C 14

YEAR	PERIOD	NUMBER OF SAMPLES	COMP TYPE	SAMPLE TIME
15 16	17 18	19 20	21	22

FILTER NUMBER	SAMPLE DATE	TOTAL AIR VOLUME m³	PARTICULATE CONC μg m³
		TOTAL	
		% FILTER	
		EQUIVALENT AIR VOLUME m³	

PARAMETER NAME	METHOD	UNITS		PARAMETER CODE	METHOD	UNITS	DP		VALUE
			23 - 32					33 - 36	
			37 - 46					47 - 50	
			51 - 60					61 - 64	
			65 - 74					75 - 78	

PARAMETER NAME	METHOD	UNITS		PARAMETER CODE	METHOD	UNITS	DP		VALUE
			23 - 32					33 - 36	
			37 - 46					47 - 50	
			51 - 60					61 - 64	
			65 - 74					75 - 78	

PARAMETER NAME	METHOD	UNITS		PARAMETER CODE	METHOD	UNITS	DP		VALUE
			23 - 32					33 - 36	
			37 - 46					47 - 50	
			51 - 60					61 - 64	
			65 - 74					75 - 78	

PARAMETER NAME	METHOD	UNITS		PARAMETER CODE	METHOD	UNITS	DP		VALUE
			23 - 32					33 - 36	
			37 - 46					47 - 50	
			51 - 60					61 - 64	
			65 - 74					75 - 78	

PARAMETER NAME	METHOD	UNITS		PARAMETER CODE	METHOD	UNITS	DP		VALUE
			23 - 32					33 - 36	
			37 - 46					47 - 50	
			51 - 60					61 - 64	
			65 - 74					75 - 78	

PARAMETER NAME	METHOD	UNITS		PARAMETER CODE	METHOD	UNITS	DP		VALUE
			23 - 32					33 - 36	
			37 - 46					47 - 50	
			51 - 60					61 - 64	
			65 - 74					75 - 78	

3.1.3 Coding Procedures

The coding procedures for each form will not be discussed in detail since the appropriate sections of AEROS User's Manual were referenced above. In addition to the AEROS User's Manual, the AEROS Manual of Codes[2] is required as a reference to code the data.

The following additional rules will help to reduce the errors identified by standard edit checks:

(1) Utilize the correct standard format to submit data.

(2) Utilize the complete 12-digit site code which was assigned by the Regional Office or the National Air Data Branch.

(3) Utilize only valid combinations of pollutant-method-interval unit codes.

(4) Code missing values as blanks and values below the minimum detectable for the sampling-analysis method as '0000'.

3.1.4 Data Flow

The lead air quality data are submitted with other air quality data in SAROAD standard input formats in the quarterly report. The complete data flow including specific data processing steps and example edit error messages is discussed in Section 7.0.0 of AEROS User's Manual.

After the data have been updated, they are available for retrieval from the data bank through routine reports which are documents in Section 2.3.0.0 of Summary and Retrieval Manual.[3]

3.1.5 References for Section 3.1

1. AEROS Manual Series Volume II: AEROS User's Manual, EPA-450/2-76-029, USEPA, OAQPS.

2. AEROS Manual Series Volume V: AEROS Manual of Codes, EPA-450/2-76-005, April, 1976, USEPA, OAQPS.

3. AEROS Manual Series Volume III: Summary and Retrieval, EPA-450/2-76-009, May, 1976, USEPA, OAQPS.

3.2 EMISSIONS DATA REPORTING

Under subpart E to 40 CFR Part 51, States are required to develop a control strategy for lead and to submit this as part of the State Implementation Plan for lead. This control strategy must include a summary of the baseline emission inventory and a detailed emissions inventory for point and area sources of lead. As indicated in subpart E, 51.86 (b), this section of the guideline describes the data formats and data bases that will be utilized to process these data and identifies the sources that must be reported.

Since the National Emissions Data System (NEDS) has the capability to store emissions for only particulate, sulfur dioxide, carbon monoxide, hydrocarbons, and nitrogen dioxide, the Hazardous and Trace Emissions System (HATREMS) has been developed to calculate and store emissions data for lead as well as other possible future criteria pollutants and noncriteria pollutants.

Although HATREMS is discussed in this section as the data base that will be utilized to store emissions data for lead, the submission of data on HATREMS point and area source forms can not currently be considered a legal requirement. After the HATREMS point and area source forms have been approved by the Office of Management and Budget (OMB), the submission of data in HATREMS format will be required and a revision sheet will be published for this document to indicate that approval has been obtained. Although not currently required, data in HATREMS format may be submitted by the control agency, and it will be stored in HATREMS. The emissions data for lead sources must be submitted in NEDS format, and the NEDS data will be utilized by HATREMS to calculate lead emissions data.

3.2.1 HATREMS System

To minimize lead emissions data collection and reporting requirements, HATREMS utilizes existing NEDS data to calculate and store lead data. Since HATREMS utilizes NEDS data, the identifiers from NEDS which include state, county, AQCR, plant, point, and source classification code (SCC) are utilized by HATREMS. In addition to utilizing NEDS point and area source data, HATREMS includes update and report programs as well as the following files: (1) point source emission factor file, (2) area source emission factor file, (3) point source emissions data file, and (4) area source emissions data file.

The point source emission factor file contains an entry for each valid SCC which emits lead. Each entry contains the following:

(1) Emission factor - emission rate of lead per unit process.
(2) Default multiplier - average lead content in the process material. This parameter is utilized the same way sulfur content is utilized to calculate SO_2 emissions.
(3) Default multiplier units - units in which the lead content is expressed (% or ppm).
(4) Control efficiency multiplier - the % of the NEDS control efficiency which is applied to lead emission.
(5) Pollutant flag - indicates the NEDS pollutant control efficiency to utilize. For lead, the particulate control efficiency will be utilized and the control efficiency multiplier will be 100.

The area source emission factor file contains an entry for each valid area source category (ASC) which emits lead; each entry contains an emission factor, a default multiplier, and the default multiplier units. These parameters are the same as the corresponding parameters in the point source emission factor file.

The point source emissions data file contains the emissions data for individual processes within plants. This file is routinely recreated by combining operating rates and control efficiencies from NEDS with emission factors from the point source emission factor file utilizing the following formula:

$$M = \frac{OR \times EF \times DM \times \frac{100-W\left(\frac{Y}{100}\right)}{100}}{2000} \qquad (1)$$

where:

M = emissions in T/Y

OR = operating rate from NEDS

EF = emission factor from HATREMS point source emission factor file

DM = default multiplier from HATREMS point source emission factor file

W = NEDS control efficiency for the pollutant flagged

Y = control efficiency multiplier from the HATREMS point source emission factor file.

As mentioned previously, the HATREMS point source emissions data file is routinely updated from NEDS data utilizing formula 1. Point source data are also manually updated as described in the following sections. Once a data record has been manually updated, data from NEDS will not override it.

The area source emissions data file contains the emissions data for each ASC for each county. This file is routinely recreated by combining area source rates from NEDS with emission factors from the area source emission factor file utilizing the following formula:

$$M = \frac{SR \times EF \times DM}{2000} \qquad (2)$$

where:

M = emissions in T/Y

SR = area source rate for individual counties

EF = emission factor from HATREMS area source emission factor file

DM = default multiplier from HATREMS area source emission factor file.

As mentioned previously, the HATREMS area source emissions data file is routinely updated from NEDS utilizing formula 2. Area source data are also manually updated as described in the following sections. Once a data record has been manually updated, data from NEDS will not override it.

Table 3.2-1 lists the data items which are utilized from NEDS as well as the data items which are stored in HATREMS. The data items which are utilized from NEDS can also be updated and stored in HATREMS utilizing the input forms which are described below.

3.2.2 HATREMS Reporting Formats

To insure that the volume of data can be automatically processed, HATREMS utilizes standarized input formats. Since HATREMS utilizes NEDS data, the input formats include Figure 3.2-1, NEDS Point Source Form, and Figure 3.2-2, NEDS Area Source Form, as well as Figure 3.2-3, HATREMS Point Source Form, and Figure 3.2-4, HATREMS Area Source Form. The NEDS point and area source forms have been utilized for several years and will not be discussed further.

The HATREMS point source form is utilized to manually update HATREMS with data which are not available from NEDS. The form defines six unique card formats for data coding. The first two cards are identical to the first two for NEDS except the card code. The other cards (3P, 4P, 5P, and 6P) allow inputting data to HATREMS which are specific to lead. Multiple

Table 3.2-1: EMISSION INVENTORY DATA FOR USE IN THE DEVELOPMENT OF Pb CONTROL STRATEGIES

			System in Which Data Will be Stored
I.	GENERAL SOURCE INFORMATION		
	A.	Establishment name and location (address and Universal Transverse Mercator grid coordinates)	NEDS
	B.	Person to contact on air pollution matters	NEDS
	C.	Source Classification Code (SCC)	NEDS
	D.	Operating Schedule 1. hours/day 2. days/week 3. week/year	NEDS
	E.	Year in which data are recorded	NEDS
	F.	Future activities (% increase in production or throughput in 10 and 20 years)	HATREMS
II.	FUEL COMBUSTION		
	A.	Number of boilers	NEDS
	B.	Type of fuel burning equipment for each boiler	NEDS
	C.	Rated capacity of each boiler, BTU/hr	NEDS
	D.	Types of fuel burned, quantities and characteristics	
		1. Type of each fuel used	NEDS
		2. Maximum quantity per hour	NEDS
		3. Average quantity per hour	HATREMS
		4. Quantity per year	NEDS
		5. Lead content of throughput	HATREMS
		6. Heat content of fuel	NEDS
	E.	Percent used for space heating and process heat	NEDS
	F.	Air Pollution control equipment	
		1. Type	NEDS
		2. Pb collection efficiency (actual), %	HATREMS

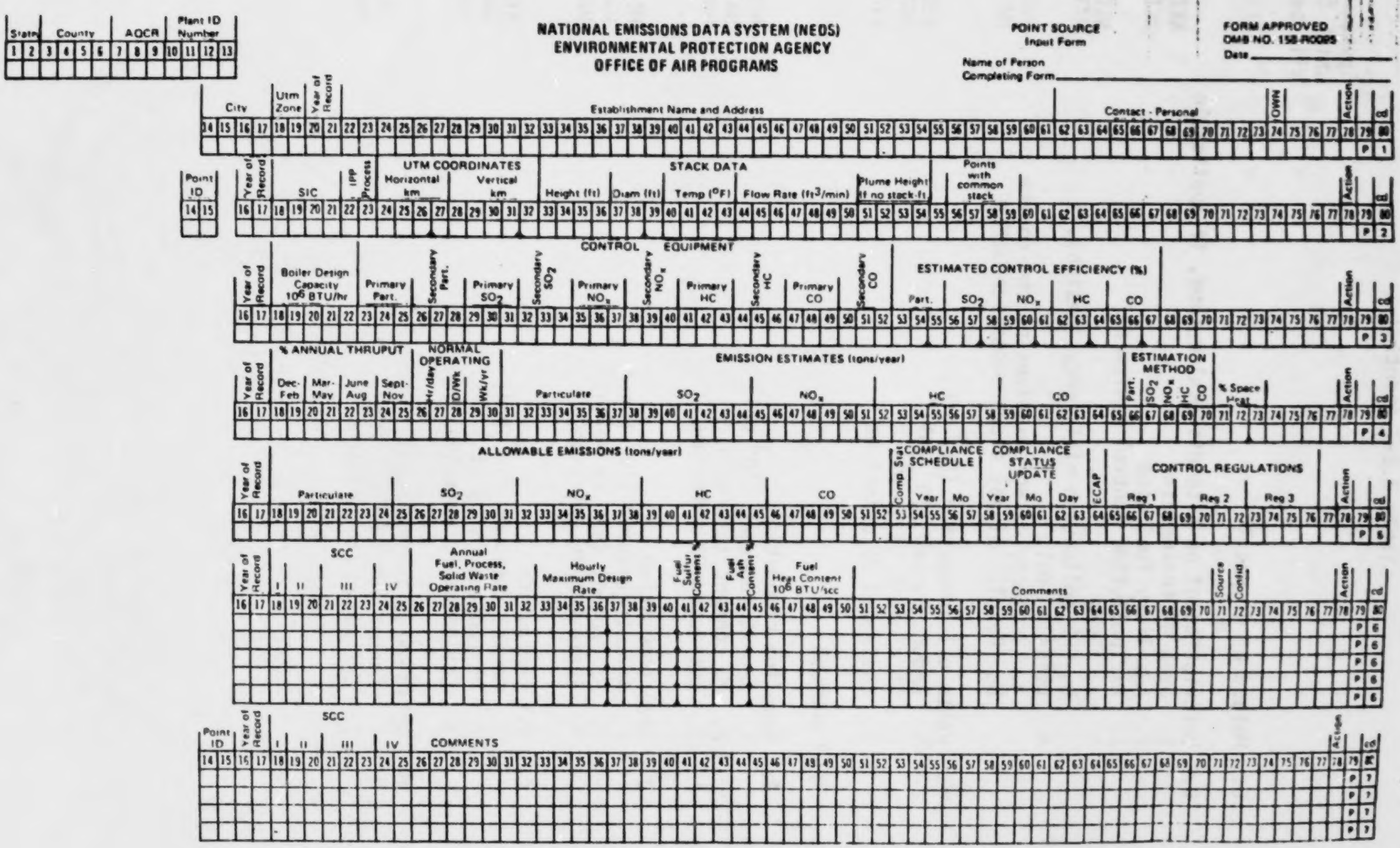
Table 3.2-1 (cont'd)

	System in Which Data Will be Stored
G. Stack data	
1. List stacks by boilers served	NEDS
2. Stack height, ft.	NEDS
3. Stack diameter (inside, top), ft.	NEDS
4. Exit gas temperature, °F	NEDS
5. Exit gas volume, cfm	NEDS
H. Emission data	
1. Estimate of Pb emissions (tons/year)	HATREMS
2. Results of any stack tests conducted (tons/year)	HATREMS
III. MANUFACTURING ACTIVITIES	
A. Process name or description for each product	NEDS
B. 1. Quantity of raw materials used and handled for each product or quantity of each product manufactured, maximum quantity per hour and average quantity per year.	NEDS
2. Pb content (% by weight) for ore crushing and grinding.	HATREMS
C. Air pollution control equipment in use	
1. Type	NEDS
2. Pb collection efficiency (actual), %	HATREMS
D. Stack data	
1. List stacks by equipment served	NEDS
2. Stack height, ft.	NEDS
3. Stack diameter (inside, top), ft.	NEDS
4. Exit gas temperature, °F	NEDS
5. Exit gas volume, cfm	NEDS
E. Emission data	
1. Estimate of Pb emissions by the source	HATREMS
2. Results of any stack tests conducted	HATREMS
IV. REFUSE DISPOSAL	
A. Amount and description of refuse generated, quantity per year	NEDS
B. Percent of total that is combustible	NEDS

Table 3.2-1 (cont'd)

	System in Which Data Will be Stored
C. Method of disposal	NEDS
D. Description of on-site disposal method, if applicable	
1. Type of incinerator	NEDS
2. Auxiliary fuel used	NEDS
3. Air pollution control equipment	
a. Type	NEDS
b. Pb collection efficiency (design), %	HATREMS
4. Emission data	
a. Estimate of Pb emissions by the source	HATREMS
b. Results of any stack tests conducted	HATREMS
E. Waste oil combustion (new SCC)	
1. Amount burned (10^3 gal)	NEDS
2. Pb content (% by wt)	HATREMS
3. Estimated Pb emissions	HATREMS
V. AREA SOURCES	
A. Gasoline combustion	
1. Amount consumed (10^3 gal)	NEDS
2. Pb content (gPb/gal)	HATREMS
3. Estimated Pb emissions	HATREMS
B. Coal combustion	
1. Amount consumed (10^3 tons)	NEDS
2. Pb content (ppm by weight)	HATREMS
3. Estimated Pb emissions	HATREMS
C. Oil combustion	
1. Amount consumed (10^3 gal)	NEDS
2. Pb content (% by wt.)	HATREMS
3. Estimated Pb emission	HATREMS
D. Solid waste incineration	
1. Amount burned (10^3 tons)	NEDS
2. Estimated Pb emissions	HATREMS

Figure 3.2-1



NATIONAL EMISSIONS DATA SYSTEM (NEDS)
ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS

POINT SOURCE
Input Form

Name of Person Completing Form ____________

FORM APPROVED
OMB NO. 158-R0095
Date ____________

State	1–2
County	3–6
AQCR	7–9
Plant ID Number	10–13

City	14–17
Utm Zone	18–19
Year of Record	20–21
Establishment Name and Address	22–61
Contact - Personal	62–73
OWN	74
	75–77
Action	78
	79: P
cd	80: 1

Point ID	14–15
Year of Record	16–17
SIC	18–21
IPP Process	22–23
UTM COORDINATES Horizontal km	24–27
UTM COORDINATES Vertical km	28–32
STACK DATA Height (ft)	33–36
STACK DATA Diam (ft)	37–39
STACK DATA Temp (°F)	40–43
STACK DATA Flow Rate (ft³/min)	44–50
Plume Height if no stack-ft	51–54
	55
Points with common stack	56–59
	60–77
Action	78
	79: P
cd	80: 2

Year of Record	16–17
Boiler Design Capacity 10^6 BTU/hr	18–22
CONTROL EQUIPMENT Primary Part.	23–25
CONTROL EQUIPMENT Secondary Part.	26–28
CONTROL EQUIPMENT Primary SO_2	29–31
CONTROL EQUIPMENT Secondary SO_2	32–34
CONTROL EQUIPMENT Primary NO_x	35–37
CONTROL EQUIPMENT Secondary NO_x	38–40
CONTROL EQUIPMENT Primary HC	41–43
CONTROL EQUIPMENT Secondary HC	44–46
CONTROL EQUIPMENT Primary CO	47–49
CONTROL EQUIPMENT Secondary CO	50–52
ESTIMATED CONTROL EFFICIENCY (%) Part.	53–55
ESTIMATED CONTROL EFFICIENCY (%) SO_2	56–58
ESTIMATED CONTROL EFFICIENCY (%) NO_x	59–61
ESTIMATED CONTROL EFFICIENCY (%) HC	62–64
ESTIMATED CONTROL EFFICIENCY (%) CO	65–67
	68–77
Action	78
	79: P
cd	80: 3

Year of Record	16–17
% ANNUAL THRUPUT Dec-Feb	18–19
% ANNUAL THRUPUT Mar-May	20–21
% ANNUAL THRUPUT June Aug	22–23
% ANNUAL THRUPUT Sept-Nov	24–25
NORMAL OPERATING Hr/day	26–27
NORMAL OPERATING D/Wk	28
NORMAL OPERATING Wk/yr	29–30
EMISSION ESTIMATES (tons/year) Particulate	31–37
EMISSION ESTIMATES (tons/year) SO_2	38–44
EMISSION ESTIMATES (tons/year) NO_x	45–51
EMISSION ESTIMATES (tons/year) HC	52–58
EMISSION ESTIMATES (tons/year) CO	59–65
ESTIMATION METHOD Part.	66
ESTIMATION METHOD SO_2	67
ESTIMATION METHOD NO_x	68
ESTIMATION METHOD HC	69
ESTIMATION METHOD CO	70
% Space Heat	71–72
	73–77
Action	78
	79: P
cd	80: 4

Year of Record	16–17
ALLOWABLE EMISSIONS (tons/year) Particulate	18–24
ALLOWABLE EMISSIONS (tons/year) SO_2	25–31
ALLOWABLE EMISSIONS (tons/year) NO_x	32–38
ALLOWABLE EMISSIONS (tons/year) HC	39–45
ALLOWABLE EMISSIONS (tons/year) CO	46–52
Comp Stat	53
COMPLIANCE SCHEDULE Year	54–55
COMPLIANCE SCHEDULE Mo	56–57
COMPLIANCE STATUS UPDATE Year	58–59
COMPLIANCE STATUS UPDATE Mo	60–61
COMPLIANCE STATUS UPDATE Day	62–63
ECAP	64
CONTROL REGULATIONS Reg 1	65–68
CONTROL REGULATIONS Reg 2	69–72
CONTROL REGULATIONS Reg 3	73–76
	77
Action	78
	79: P
cd	80: 5

Year of Record	16–17
SCC I	18
SCC II	19–20
SCC III	21–23
SCC IV	24–25
Annual Fuel, Process, Solid Waste Operating Rate	26–32
Hourly Maximum Design Rate	33–39
Fuel Sulfur Content %	40–42
Fuel Ash Content %	43–45
Fuel Heat Content 10^6 BTU/scc	46–50
Comments	51–70
Source	71
Confid	72
	73–77
Action	78
	79: P (5 lines)
cd	80: 6 (5 lines)

Point ID	14–15
Year of Record	16–17
SCC I	18
SCC II	19–20
SCC III	21–23
SCC IV	24–25
COMMENTS	26–77
Action	78
	79: P (5 lines)
cd	80: 7 (5 lines)

Figure 3.2-2

NATIONAL EMISSIONS DATA SYSTEM (NEDS)
ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS

AREA SOURCE
Input Form
Date ____________

FORM APPROVED
OMB NO. 158-R0095

Name of Person Completing Form ______________________

State	County	AQCR
1 2	3 4 5 6	7 8 9

Year of Record	SIP EMISSION ESTIMATES (10^2 tons/yr)					SULFUR CONTENT (%)				ASH CONTENT (%)		RESIDENTIAL FUEL						Action		cd
	Particulate	SO_2	NO_x	HC	CO	Anth. Coal	Bitum. Coal	Dist. Oil	Resid. Oil	Anth. Coal	Bitum. Coal	Anth. Coal 10^1 tons	Bitumin. Coal 10^1 tons	Dist. Oil 10^4 Gal.	Resid. Oil 10^4 Gal.	Nat. Gas 10^7 ft.^{3}	Wood 10^2 tons			
10 11	12 13 14 15 16	17 18 19 20	21 22 23 24	25 26 27 28 29	30 31 32 33 34	35 36	37 38	39 40	41 42	43 44 45	46 47 48	49 50 51 52 53	54 55 56 57 58 59	60 61 62 63 64	65 66 67 68	69 70 71 72 73	74 75 76 77	78	79	80
																			A	1

COMMERCIAL AND INSTITUTIONAL FUEL						INDUSTRIAL FUEL									Action		cd
Anth. 10^1 tons	Bitumin. 10^1 tons	Dist. Oil 10^4 Gals.	Resid. Oil 10^4 Gals.	Nat. Gas 10^7 Ft^3	Wood 10^2tons	Anth. Coal 10^1 tons	Bitum. Coal 10^1 tons	Coke 10^1 tons	Dist. Oil 10^4 Gals.	Resid. Oil 10^4 Gals.	Nat. Gas 10^7 Ft.^{3}	Wood 10^2 tons	Process Gas 10^7 ft^3				
10 11 12 13 14	15 16 17 18 19	20 21 22 23 24	25 26 27 28 29	30 31 32 33	34 35	36 37 38 39 40 41	42 43 44 45 46 47	48 49 50 51	52 53 54 55 56	57 58 59 60 61	62 63 64 65 66	67 68 69	70 71 72 73	74 75 76 77	78	79	80
																A	2

ON SITE INCINERATION			OPEN BURNING			GASOLINE FUEL			DIESEL FUEL			Pop Code	Action		cd
Residential 10^1 tons	Industrial 10^2 tons	Comm. Inst. 10^2 tons	Residential 10^2 tons	Industrial 10^2 tons	Comm'l - Instit'l. 10^2 tons	Light Vehicle 10^3 Gals.	Heavy Vehicle 10^3 Gals.	Off Hiway 10^3 Gals.	Heavy Vehicle 10^3 Gals.	Off Hiway 10^4 Gals.	Rail Locomotive 10^4 Gals.				
10 11 12 13 14 15	16 17 18 19 20	21 22 23 24	25 26 27 28 29 30	31 32 33 34 35 36	37 38 39 40 41	42 43 44 45 46 47 48	49 50 51 52 53 54	55 56 57 58 59 60	61 62 63 64 65 66	67 68 69 70 71	72 73 74 75 76	77	78	79	80
														A	3

AIRCRAFT			VESSELS				EVAPORATION		MEASURED VEHICLE MILES				Action		cd
Military LTO CYC 10^2	Civil LTO CYC 10^1	Commercial LTO CYC 10^1	Coal 10^1 tons	Diesel Oil 10^4 Gals.	Resid. Oil 10^4 Gals.	Gasoline 10^3 Gals	Solvent Purchased tons yr	Gasoline Marketed 10^5 Gals.	Limited Access Road 10^4 Miles	Rural Roads 10^4 Miles	Suburban Roads 10^4 Miles	Urban Roads 10^4 Miles			
10 11 12 13	14 15 16 17 18 19	20 21 22 23 24	25 26 27 28	29 30 31 32	33 34 35 36 37	38 39 40 41	42 43 44 45 46 47	48 49 50 51 52	53 54 55 56 57 58	59 60 61 62 63 64	65 66 67 68 69 70	71 72 73 74 75 76 77	78	79	80
														A	4

					FOREST WILDFIRES		MANAGED BURNING (Slash/Prescribed Burning)		AGRICULTURAL FIELD BURNING		FROST CONTROL 10^2		STRUCTURE FIRES	Action		cd
Dirt Roads Traveled 10^3 Vehicle miles	Dirt Air Strips LTO CYCLES	Construction Acres	Miscellaneous Wind Erosion 10^3 Acres	Land Tilling 10^3 Acres	Acres Burned	Tons/acres Burned	Acres Burned	Tons/Acres Burned	Acres Burned	Tons/Acres Burned	Orchard Heaters Operating	Days/Fired Days/year	Fires/year			
10 11 12 13 14 15 16	17 18 19 20 21	22 23 24 25 26 27	28 29 30 31 32	33 34 35 36 37	38 39 40 41 42 43 44	45 46 47	48 49 50 51 52 53	54 55 56	57 58 59 60 61 62	63 64 65	66 67 68 69	70 71 72	73 74 75 76 77	78	79	80
															A	5

COMMENTS	Action		cd
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77	78	79	80
		A	6

EPA (DUR) 219
3/72

Figure 3.2-3

HAZARDOUS AND TRACE EMISSIONS SYSTEM
(HATREMS)

STATE	COUNTY	AQCR	PLANT ID NUMBER
1 2	3 4 5 6	7 8 9	10 11 12 13

POINT SOURCE INPUT FORM   DATE ____________

NAME OF PERSON COMPLETING FORM ____________________

CITY	UTM ZONE	YEAR OF RECORD	ESTABLISHMENT NAME AND ADDRESS	CONTACT- PERSONAL	OWN		ACTION	CARD CODE	
14 15 16 17	18 19	20 21	22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	62 63 64 65 66 67 68 69 70 71 72 73	74	75 76 77	78	79	80
								1	P

POINT ID	YEAR OF RECORD	SIC	IPP PROCESS	UTM COORDINATES HORIZONTAL Km	UTM COORDINATES VERTICAL Km	STACK DATA HEIGHT(ft)	STACK DATA DIAM(ft)	STACK DATA TEMP(°F)	STACK DATA FLOW RATE (ft^3/min)	PLUME HEIGHT IF NO STACK-ft		POINTS WITH STACK		ACTION	CARD CODE	
14 15	16 17	18 19 20 21	22 23	24 25 26 27	28 29 30 31 32	33 34 35 36	37 38 39	40 41 42 43	44 45 46 47 48 49 50	51 52 53	54	55 56 57 58 59	60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77	78	79	80
															2	P

POINT ID	YEAR OF RECORD	CONTROL EQUIP. FIRST	CONTROL EQUIP. SECOND	CONTROL EQUIP. THIRD	ANNUAL THRUPUT DEC FEB	ANNUAL THRUPUT MAR MAY	ANNUAL THRUPUT JUNE AUG	ANNUAL THRUPUT SEPT NOV	NORMAL OPERATING hr/day	NORMAL OPERATING day/wk	NORMAL OPERATING wk/yr	COMMENTS	ACTION	CARD CODE	
14 15	16 17	18 19 20	21 22 23	24 25 26	27 28	29 30	31 32	33 34	35 36	37	38 39	40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77	78	79	80
														3	P

POINT ID	YEAR OF RECORD	SCC I	SCC II	SCC III	SCC IV	FUEL, PROCESS SOLID WASTE OPERATING RATE	Hourly MAXIMUM DESIGN RATE	Hourly Average Design Rate	% Growth 10Y	20Y	COMMENTS	ACTION	CARD CODE	
14 15	16 17	18	19 20	21 22 23	24 25	26 27 28 29 30 31 32	33 34 35 36 37 38 39	40 41 42 43 44 45 46	47 48 49	50 51 52	53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77	78	79	80
													4	P

POINT ID	YEAR OF RECORD	SCC I	SCC II	SCC III	SCC IV	POLLUTANT	ANL. MTHD.	CONTROL EQUIP. EFFICIENCY	METHOD	EMISSION PARAMETER + −	METHOD	EMISSION TON/ YR + −	METHOD		Particulate Flag COMMENTS	ACTION	CARD CODE	
14 15	16 17	18	19 20	21 22 23	24 25	26 27 28 29 30	31	32 33 34 35 36	37	38 39 40 41	42	43 44 45 46 47	48	49	50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77	78	79	80
																	5	P

POINT ID	YEAR OF RECORD			COMMENTS	ACTION	CARD CODE	
14 15	16 17	18 19 20 21 22 23 24 25	26 27 28 29 30	31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77	78	79	80
						6	P

THE 4 FIELDS IN COLS. 14 THROUGH 30 ARE OPTIONAL FOR CARD 6P, BUT COLS. 1-13 ARE ALWAYS REQUIRED.

Figure 3.2-4

AREA SOURCE INPUT

1-10				11-20		21-30		31-40	41-50 51-60 61-70 71-80		
State	County	AQCR	ASC	Pollutant Code	YR OF REC	Source Rate	Source Activity Factor	Emissions (T/Year)	Comments	ACTION	IA
										A	I,A

cards 4P, 5P, and 6P are for multiple processes per point, multiple pollutants other than lead per process, and multiple comments at the point, process, and pollutant level.

The HATREMS area source form is utilized to supplement NEDS area source data. The form describes only one card which may be input for each area source category pollutant combination per county which is reported.

3.2.3 Coding Procedures

To insure that the data are correctly coded, the coding procedures for NEDS and HATREMS which appear in AEROS Users Manual1 should be utilized. Codes which are necessary to complete the forms are located in AEROS Manual of Codes.2

Table 3.2-1 lists the data items which must be collected. Since HATREMS utilizes NEDS for specific data items, sources of lead must be coded and updated in NEDS as well as HATREMS. Since NEDS coding procedures have been utilized for several years, no further discussion will be given. The control agency must insure that the NEDS data are correctly coded because they will be utilized by HATREMS.

The coding procedures for the HATREMS point source form are given in Section 3.6.2 of AEROS User's Manual.1 These instructions are general for all HATREMS coding, and the following additional instructions should also be followed for lead:

(1) Since HATREMS utilizes NEDS data and a NEDS form must be submitted for each lead source, cards 1P and 2P are not required for lead sources in NEDS. Card 3P is not required unless a third control device exists. In order for HATREMS to utilize NEDS data, the HATREMS identifier (state, county, plant, point, SCC) must be the same as the NEDS identifier.

(2) All individual data items on cards 4P and 5P must be manually updated. When any data on 4P or 5P are updated, the remaining data for cards 1P-5P of that point are transfered from NEDS to HATREMS. After these data are transfered from NEDS, all future updates for that point must be manually input utilizing the HATREMS point source form and the correct update action code.

The coding procedures for the HATREMS area source form are given in Section 3.6.1 of AEROS User's Manual.[1] These instructions are general for all HATREMS coding and apply for lead data.

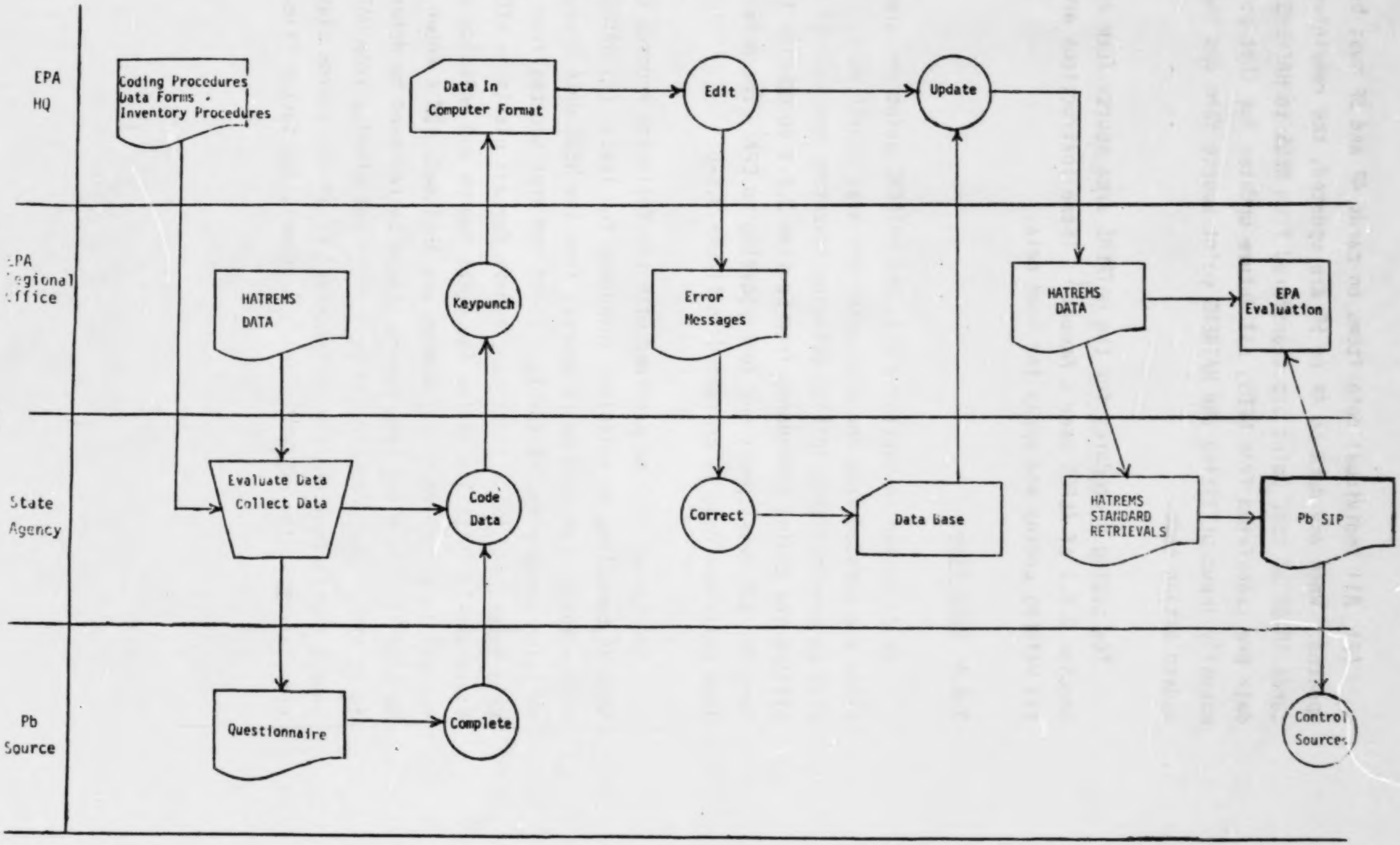
3.2.4 Data Flow

As discussed in Section 3.2.1, the HATREMS point and area source data files are created from the NEDS point and area source data. The States will be provided this initial emission inventory and will be required to utilize the coding procedures from Section 3.2.3 to compile the lead inventory for SIP development and for reporting to EPA. The data flow for the lead emissions data is presented in Figure 3.2-5.

The States will be provided with the following reports to assist them in compiling an emissions inventory for lead: (1) HATREMS point source report for lead point sources from the NEDS data base, (2) HATREMS emission summary report for lead point and area sources from the NEDS data bases, and (3) a plant name report for all plants in NEDS. The State should initially review the point source and emission summary reports to ensure that all sources are included. If a known lead source is missing, the plant name report should be reviewed to determine if it is in NEDS. The source could be in NEDS but missing from HATREMS if the source classification code is incorrect or if the source classification code is not in the HATREMS point source emission factor file.

Figure 3.2-5

LEAD EMISSIONS DATA FLOW



The States must code and submit NEDS and HATREMS point source forms for all sources of lead that emit five tons or more per year to update the emission inventory to the common base year which was utilized in the strategy development. The States must code and submit NEDS and HATREMS area source forms for all counties for which the data were collected for the demonstration of attainment. The NEDS forms must be completed to update existing sources and add new sources to produce a lead emission inventory for a common base year. The HATREMS form must be completed to supply data which can not be stored in NEDS.

The NEDS and HATREMS forms or computer readable format will be submitted to the appropriate Regional Office. The NEDS data will be routinely processed utilizing the procedures defined in AEROS Users' Manual. These data will be updated on the standard monthly update schedule. The HATREMS data will be converted to computer readable format and forwarded to the National Air Data Bank. These data will be updated to HATREMS on a standard schedule.

The HATREMS report programs will be provided to the Regional Office NEDS contact to provide data requests to States as well as the other user community. New report programs will be developed as requested by the user and identified as being useful.

3.2.5 References for Section 3.2

1. AEROS Manual Series, Volume II: AEROS Users' Manual, EPA-450/2-76-029, December 1976, USEPA, OAQPS.
2. AEROS Manual Series, Volume V: AEROS Manual of Codes, EPA-450/2-76-005, April 1976, USEPA, OAQPS.
3. AEROS Manual Series, Volume III: Summary and Retrieval, EPA-450/2-76-009, May 1976, USEPA, OAQPS.
4. Development of HATREMS Data Base and Emission Inventory Evaluation, EPA-450/3-77-011, April, 1977, USEPA, OAQPS.

4.0 ANALYSIS AND CONTROL STRATEGY DEVELOPMENT

As indicated above in section 2.2, detailed guidance on the process of analysis and control strategy development appears in EPA's Air Quality Analysis Workshop, Volume 1--Manual.[1]

4.1 BACKGROUND CONCENTRATIONS

Natural concentrations of lead in the air have been estimated[2] to be about 0.0006 $\mu g/m^3$ resulting mainly from airborne dust containing 10 to 15 ppm of lead.[3] Chow, et al.,[4] have recommended that 0.008 $\mu g/m^3$ be considered as the baseline concentration for atmospheric lead for the continental United States. Most areas, however, will experience greater concentrations that cannot be accounted for by sources in the immediate vicinity or by natural background. The majority of these concentrations not accounted for by nearby sources or background can probably be attributed to airborne lead transported from sources outside the study area in question. Therefore, a plan to control emissions in the study area will not reduce the concentrations due to the outside sources. To account for the phenomenon of transport of lead particulate matter from outside the study area,

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[1] Cirillo, R.R., et al., Air Quality Analysis Workshop, Volume 1--Manual. Prepared for the Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, N.C. 27711. November 1975. (EPA-450/3-75-080a).

[2] Patterson, C.C., Contaminated and Natural Lead Environments of Man. Archives of Environmental Health. 11:334-363, 1965.

[3] Chow, T.J., and C.C. Patterson. The Occurrence and Significance of Lead Isotopes in Pelagic Sediments. Geochim. Cosmochim. Act. (London). 26:263-308. 1962.

[4] Chow, T.J., et al., Lead Aerosol Baseline: Concentration at White Mountain and Laguna Mountain, California. Science 178:401-402. October 1972.

States should assume a "background" equal to the levels of airborne lead in a representative nonurban area that is not significantly influenced by stationary or mobile lead sources.

For the purposes of SIP development, States may account for the future reduction of background lead concentrations that may result from the federal programs for the reduction of lead in gasoline, the prohibition of the use of leaded gasoline in catalyst-equipped vehicles, and reduced gasoline consumption in vehicles in future years.

States should discuss their choice of background lead concentrations with cognizant persons in the appropriate EPA Regional Offices.

4.2 LEAD EMISSION FACTORS

In performing the analysis to determine whether an area needs a control strategy to attain and maintain the national air quality standard for lead, a State will have to compile an inventory of lead emission sources and the quantity of emissions produced by each source. Emission factors that relate source activity to the quantity of emissions appear in EPA's Control Techniques for Lead Air Emissions,[5] and two other reports concerning lead emissions.[6,7] One of these reports[6] also describes procedures by which States can quantify fugitive lead emissions from stationary sources; that report also provides additional references[8,9,10,11] on the quantification of fugitive emissions. The other report[7] provides emission factors for resuspended lead dust from paved roads.

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[5] Control Techniques for Lead Air Emissions. PEDCo Environmental, Inc., Cincinnati, Ohio. Prepared for the U.S. Environmental Protection Agency, National Environmental Research Center under Contract No. 68-02-1375, Task Order No. 32. January 1977. Report No. EPA-450/2-77-012.

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[6] Zoller, John M., et al. A Method for Characterization and Quantification of Fugitive Lead Emissions from Secondary Lead Smelters, Ferroalloy Plants, and Gray Iron Foundries. Prepared by PEDCo Environmental, Inc., for the U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. January 1978. EPA-450/3-78-003. (Currently under revision; copies not available as of this printing.)

[7] Maxwell, Christine M., and Daniel W. Nelson. A Lead Emission Factor for Reentrained Dust from a Paved Roadway. Prepared by Midwest Research Institute for the U.S. Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711. April 1978. EPA-450/3-78-021.

[8] Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions, PEDCo Environmental, Inc., Cincinnati, Ohio. Prepared for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, under Contract No. 68-02-1375, Task Order No. 33. Publication No. EPA-450/3-77-010. March 1977.

[9] Technical Manual for the Measurement of Fugitive Emissions: Upwind-Downwind Sampling Method for Industrial Fugitive Emissions. U.S. Environmental Protection Agency, Industrial and Environmental Research Laboratory, Research Triangle Park, N.C., April 1976. Publication No. EPA-600/2-76-089a.

[10] Technical Manual for the Measurement of Fugitive Emissions: Roof Monitor Sampling Method for Industrial Fugitive Emissions. U.S. Environmental Protection Agency, Industrial and Environmental Research Laboratory, Research Triangle Park, N.C., May 1976. Publication No. EPA-600/2-76-089b.

[11] Technical Manual for Measurement of Fugitive Emissions: Quasi-Stack Sampling Method for Industrial Fugitive Emissions. U.S. Environmental Protection Agency, Industrial and Environmental Research Laboratory, Research Triangle Park, N.C., May 1976. Publication No. EPA-600/2-76-089c.

4.3 PROJECTING AUTOMOTIVE LEAD EMISSIONS

Lead emissions from mobile sources are calculated based on emissions at different vehicle speeds, the lead content of gasoline, and an average fleet fuel economy. The lead content of gasoline and fuel economy are a function of the calendar year of interest. The background for the computation procedure presented below appears in Appendix C of this guideline. Appendix C also presents lead emission rates for seven example roadway configurations.

4.3.1 Lead Emissions from Automobiles

4.3.1.1 Individual Roadways--The emission rate from automotive sources from an individual roadway (line source) is calculated by the following equation:

$$e_{n,s} = \frac{a_s Pb_n T}{f_{n,s}} \qquad (1)$$

where: $e_{n,s}$ = emission rate for calendar year n and speed s (g/road mile-day);

a_s = percentage of lead burned that is exhausted; available from Figure 4.3-1 (nondimensional; expressed as a decimal); for roadway portions subject to full-throttle acceleration (0-60 mph), assume $a_s = 10.0$;

Pb_n = probable pooled average lead content of gasoline in year n from Table 4.3-1 (g/gal);

T = average daily traffic (vehicles/day);

$f_{n,s}$ = average fleet fuel economy for calendar year n and speed s; calculation described below (vehicle-road mile/gal).

To calculate the emission rate in units of grams/meter-second, $e_{n,s}$ can be corrected by dividing by 1.39×10^8.

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The term, $f_{n,s}$ is calculated by the following equation; the calculation is based on a base year of 1974:

$$f_{n,s} = \left[\frac{\sum_{i=1967}^{1974} [C_{s,i} E_{c,i} m_i]}{E_{74}} \right] E_n C_t \qquad (2)$$

where: $C_{s,i}$ = speed-dependent fuel economy correction factor for model year i; calculation is described below in equation (3) (nondimensional);

$E_{c,i}$ = city/highway combined fuel economy for model year i from Table 4.3-3 (mi./gal.);

m_i = fraction of annual travel by model year i vehicles from Table 4.3-4; assume 1974 model year vehicles are one year old, 1973 model year vehicles are two years old, etc. (nondimensional);

E_{74} = base year (1974) fuel economy from Table 4.3-2 (mi./gal.);

E_n = average fleet fuel economy for projection year n from Table 4.3-2 (mi./gal.);

C_t = traffic flow correction factor; C_t = 1.2297 for free-flow traffic; C_t = 0.866 for city (stop-and-go) traffic (nondimensional).

$C_{s,i}$, the nondimensional speed-dependent fuel economy correction factor for model year i, is calculated by the following equation:

$$C_{s,i} = \sum_{j=0}^{4} A_j S^j \qquad (3)$$

where: A = correction factors from Table 4.3-5;

S = vehicle speed (miles/hour). [Note: $S^0 = 1$.]

To simplify computation, the values of $C_{s,i}$ are reproduced in Table 4.3-6 and the values of $\sum_{i=1967}^{1974} C_{s,i} E_{c,i} m_i$ are reproduced in tabular form in Table 4.3-7 and in graphical form in Figure 4.3-2.

4.3.1.2 Area Source Automotive Emissions--Equation (1) may be used to calculate automotive emissions as area sources rather than specific line sources, but the term "T" should be replaced, with the term "V", the daily vehicle-miles traveled (VMT) in the area (vehicle-miles/day). This substitution enables the user to employ VMT data, which is more readily available for area mobile sources than average daily traffic. Also, the term $e_{n,s}$ will now be expressed in g/day. The determination of a_s and $f_{n,s}$ should be based on the average vehicle speed for the specific area.

4.3.2 Lead Emissions from Other Gasoline Powered Vehicles

Motorcycles and diesel-powered vehicles are assumed to emit quantities of lead that are insignificant compared to other gasoline-powered vehicles.

There are no known measurements of lead emissions from either light- or heavy-duty trucks. Therefore, for purposes of calculating emissions, the percentage of lead burned that is exhausted from these vehicles at various speeds is assumed to be the same as that for automobiles (Figure 4.3-1).

Light-duty gasoline-powered trucks are assumed to have the same gasoline economy as automobiles; new light-duty trucks are assumed to require the use of non-leaded gasoline to meet emissions standards for CO and hydrocarbons through the use of catalysts. Therefore, the emission rate for light-duty gasoline-powered trucks is calculated using the same procedures and parameters as for automobiles.

Heavy-duty gasoline-powered trucks are assumed to burn leaded gasoline for all future years. Also, their fuel economy is different from that of light-duty trucks. Therefore, the emission rate for heavy-duty gasoline-powered trucks is calculated by equation 1, but the following parameters are modified:

Pb_n = probable lead content of leaded gasoline in year n from Table 4.3-8.

f_n = average fleet fuel economy in calendar year n = 5.7 miles/gal (taken from Kennedy, G.J., et al. Exhaust Emissions from Heavy-Duty Trucks Testing on a Road Course and by Dynamometer. Society of Automotive Engineers, Automobile Engineering Meeting, Detroit, Mich., October 13-17, 1975).

4.3.3 Example Calculation of Automobile Lead Emissions

Problem: For a city street with a speed of 16 miles per hour and average daily traffic of 28,000 vehicles, calculate the lead emission rate for the year 1983.

Solution: We use Equation (1):

$$e_{83,16} = \frac{a_{16} Pb_{83} T}{f_{83,16}} . \qquad (1A)$$

From Figure 4.3-1, for a cruise speed of 16 mph, we find that approximately 10.5 percent of the lead being burned is emitted. Therefore, a_{16} = 0.105.

From Table 4.3-1, we find that Pb_{83}, the probable pooled average lead content for 1983, is estimated to be 0.25 g/gal.

We are given the average daily traffic, T, as 28,000 vehicles/day.

We must now calculate the average fleet fuel economy for 1983 by using Equation 2:

$$f_{83,16} = \left[\sum_{i=1967}^{1974} [C_{16,i} E_{c,i} m_i] \right] \frac{E_{83} C_t}{E_{74}} . \qquad (2A)$$

To do this, however, we must first calculate $C_{16,i}$, the speed-dependent fuel economy correction factor for model years 1967 through 1974 using Equation (3):

$$C_{16,i} = \sum_{j=0}^{4} A_j (16)^j \qquad (3A)$$

The A_j coefficients appear in Table 4.3-5. Table 4.3-9 presents the results of that calculation. That table also presents the values for $E_{c,i}$ from Table 4.3-3 and m_i from Table 4.3-4 for each model year, together with the product of these three factors and the sum of the products. As Table 4.3-9 indicates,

$$\sum_{i=1967}^{1974} C_{16,i}E_{c,i}m_i = 11.34.$$

The factors E_{74} and E_{83} from Equation (2A) are found in Table 4.3-2; E_{74} = 12.4 vehicle-road mi./gal. and E_{83} = 19.1 vehicle-road mi./gal. Since the roadway is a city street, the traffic flow correction factor C_t = 0.866. Substituting this information into Equation (2A), we obtain:

$$f_{83,16} = \frac{11.34}{12.4} \times 19.1 \times 0.866$$

$$= 15.1 \text{ vehicle-road mi./gal.}$$

Substituting the above results into equation (1A), we obtain:

$$e_{83,16} = \frac{0.105 \times 0.25 \text{ g/gal} \times 28 \times 10^3 \text{ vehicles/day}}{15.1 \text{ vehicle-road miles/gal.}}$$

$$= 48.7 \text{ g/road mile-day.}$$

In units of g/m-sec, this becomes

$$e_{83,16} = \frac{48.7}{1.39 \times 10^8} = 3.50 \times 10^{-7} \text{ g/m-sec.}$$

Figure 4.3-1

PERCENTAGE OF BURNED LEAD EXHAUSTED
vs.
VEHICLE CRUISE SPEED

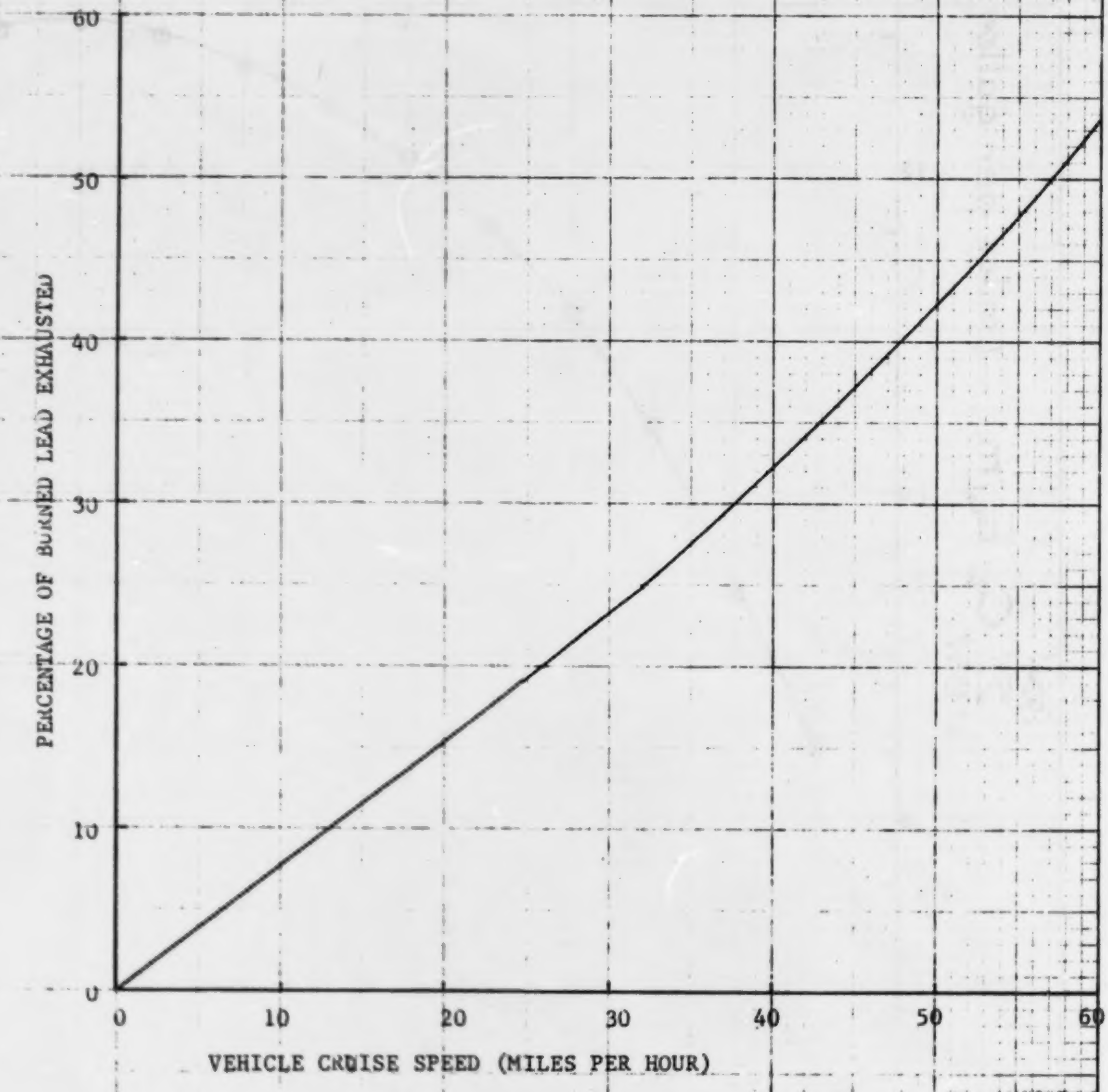

FIGURE 4.3-2

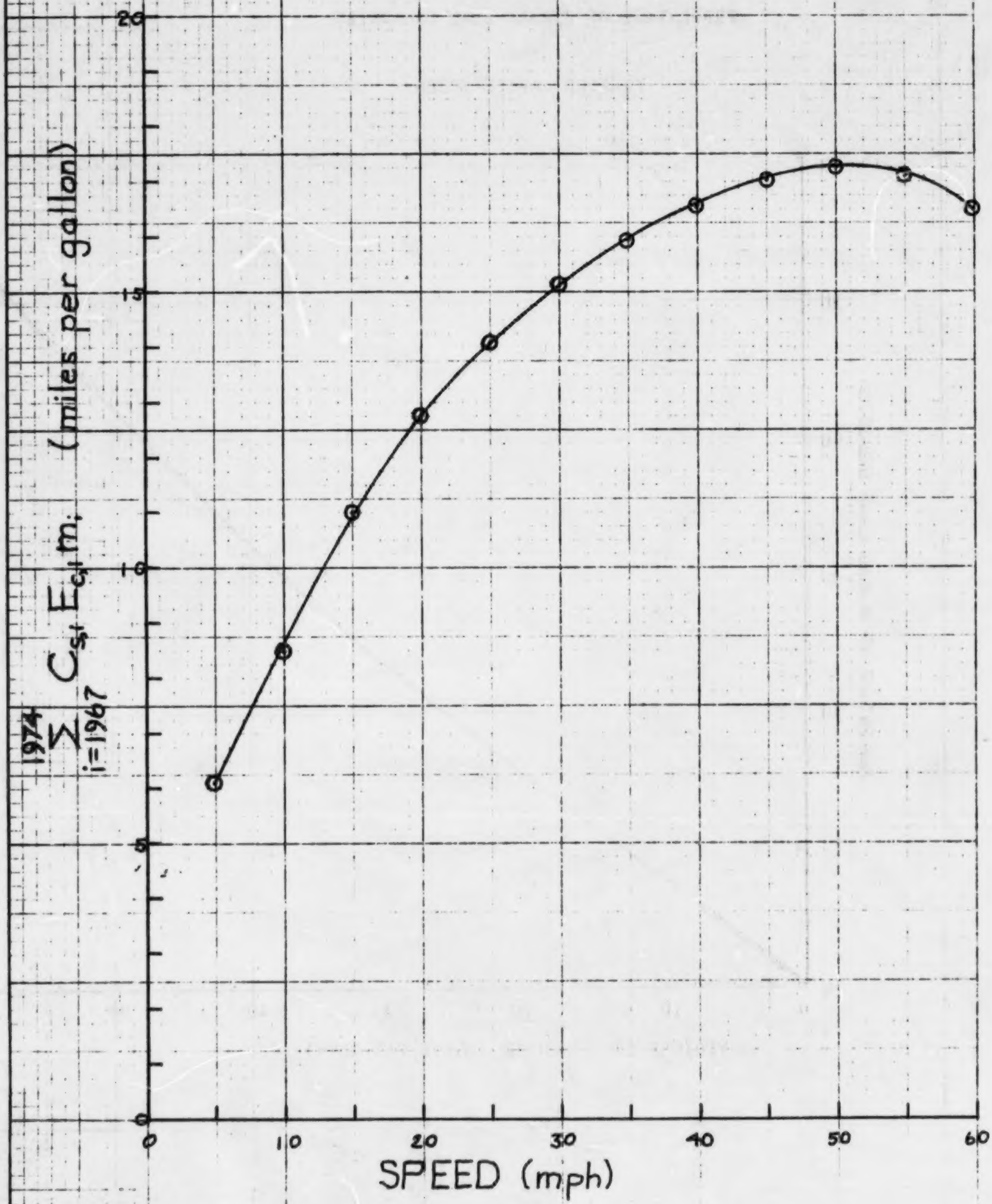
$\sum_{i=1967}^{1974} C_{s,i} E_{c,i} m_i$ (miles per gallon)
20
15
10
5
0
0
10
20
30
40
50
60
SPEED (mph)

TABLE 4.3-1

PROBABLE POOLED AVERAGE LEAD CONTENT OF GASOLINE

(grams/gal)

Year	Lead Content
1974	2.0
1975	1.7
1976	1.4
1977	1.0
1978	0.8
1979	0.5
1980	0.5
1981	0.5
1982	0.34
1983	0.25
1984	0.19
1985	0.15
1986	0.13
1987	0.11
1988	0.09
1989	0.08
1990	0.05

TABLE 4.3-2

AVERAGE FLEET FUEL ECONOMY

(miles/gallon)

Calendar Year	Fuel Economy
1974	12.4
1977	13.3
1978	14.0
1979	14.8
1980	15.7
1981	16.8
1983	19.1
1985	21.7
1990	26.2
1995	27.4

Ref: U.S. Environmental Protection Agency, A Report on Automotive Fuel Economy, Washington, D.C., February, 1974.

15 USC 2002, enacted December 22, 1975.

TABLE 4.3-3

CITY/HIGHWAY COMBINED FUEL ECONOMY

(miles/gallon)

Model Year	Fuel Economy
1974	15.15
1973	14.89
1972	15.20
1971	15.24
1970	15.42
1969	15.47
1968	15.60
1967	16.15

TABLE 4.3-4

FRACTION OF ANNUAL LIGHT-DUTY VEHICLE TRAVEL BY MODEL YEAR

Age Years	Fraction of Annual Travel
1	.112
2	.143
3	.130
4	.121
5	.108
6	.094
7	.079
≥8	.213

Ref: AP-42, Supplement 5

TABLE 4.3-5

FUEL ECONOMY CORRECTION FACTORS BY MODEL YEAR

(NORMALIZED TO 32.7 MILES/HOUR)

Model Year	A_0	A_1	A_2	A_3	A_4
Pre-controlled	2.4697E-2	7.55258E-2	-2.42452E-3	4.01469E-5	-2.68893E-7
1968	1.75941E-2	6.90954E-2	-2.01359E-3	3.19426E-5	-2.12343E-7
1969	3.43032E-3	7.24956E-2	-2.18976E-3	3.54015E-5	-2.36485E-7
1970	6.00124E-3	6.90443E-2	-1.98463E-3	3.13931E-5	-2.09286E-7
1971	9.76255E-3	6.84494E-2	-1.96781E-3	3.13719E-5	-2.11167E-7
1972	8.57745E-2	7.0882E-2	-2.15219E-3	3.57324E-5	-2.44316E-7
1973-74	6.29988E-2	5.96559E-2	-1.59874E-3	2.59441E-5	-1.84877E-7

Ref: AP-42, Supplement 8

Fuel Economy Correction Factor = $A_0+A_1S+A_2S^2+A_3S^3+A_4S^4$

where S = vehicle speed

TABLE 4.3-6

$C_{s,i}$ VALUES

YEAR:	1967	1968	1969	1970	1971	1972	1973/4
SPEED (MPH)							
5	.347	.317	.315	.305	.307	.391	.324
10	.575	.537	.542	.527	.527	.613	.524
15	.734	.698	.706	.690	.689	.773	.676
20	.844	.816	.823	.811	.809	.889	.795
25	.920	.903	.908	.900	.899	.976	.888
30	.975	.963	.972	.969	.968	1.042	.965
35	1.016	1.020	1.021	1.023	1.023	1.098	1.027
40	1.048	1.060	1.060	1.066	1.066	1.139	1.078
45	1.069	1.089	1.088	1.097	1.098	1.172	1.116
50	1.077	1.104	1.101	1.113	1.114	1.189	1.136
55	1.063	1.098	1.093	1.108	1.109	1.183	1.133
60	1.015	1.062	1.052	1.073	1.072	1.143	1.095

TABLE 4.3-7

VALUES OF $\sum_{i-1967}^{1974} C_{s,i} E_{c,i} m_i$

Speed (MPH)	Value
5	5.13
10	8.49
15	10.95
20	12.74
25	14.08
30	15.11
35	15.92
40	16.57
45	17.04
50	17.27
55	17.16
60	16.54

TABLE 4.3-8

PROBABLE LEAD CONTENT OF LEADED GASOLINE*
(grams/gal)

Year	Lead Content
1974	2.0
1975	1.9
1976	1.9
1977	1.6
1978	1.6
1979	1.2
1980	1.6
1981 and beyond	2.0

*Source: Appendix C of this Guideline, Table 5.

TABLE 4.3-9

CALCULATION OF $\sum_{i=1967}^{1974} C_{16,i}E_{c,i}m_i$ FOR EXAMPLE CALCULATION

Model Year	Fuel Economy Speed Correction Factors $C_{16,i}$	City/Highway Combined Fuel Economy $E_{c,i}$	Fraction of Annual LDV Travel by Model Year m_i	1974 Fuel Economy at 16 mph $C_{16}E_{c,i}m_i$
pre-1968	0.759	16.15	0.213	2.61
1968	0.725	15.60	0.079	0.893
1969	0.732	15.47	0.094	1.06
1970	0.718	15.42	0.108	1.20
1971	0.716	15.24	0.121	1.32
1972	0.799	15.20	0.130	1.58
1973	0.702	14.89	0.143	1.49
1974	0.702	15.15	0.112	1.19

$\sum = 11.34$

4.4 AIR QUALITY MODELING

4.4.1 Modeling in Certain Areas

Sections 51.83 and 51.85 of 40 CFR Part 51 require a demonstration of attainment using a modified rollback model as a minimum, but provide that a dispersion model may be used if desired. Section 51.83 requires the analysis of an entire urbanized area if that area has measured lead concentrations in excess of 4.0 $\mu g/m^3$, quarterly mean, measured since January 1, 1974. Section 51.85 requires an analysis of the area in the vicinity of any air quality monitor that has recorded lead concentrations in excess of the lead national standard concentration.

Based solely on national data available to EPA, EPA estimates that there are few areas that have concentrations greater than the standard concentration and fewer still with concentrations greater than 4.0 $\mu g/m^3$, quarterly mean. There are other data available to State and local air pollution control agencies, however, that may indicate that other areas have concentrations in excess of the concentrations specified in the criteria for performing the analysis. Many areas have already been analyzed for other pollutants using dispersion models and therefore, some of the work needed to run a dispersion model for lead, such as allocation of area source emissions, may have already been done. For such areas, EPA encourages appropriate States to employ a dispersion model where possible, since such a model will generally yield more accurate estimates of air quality concentrations.

Where States elect to use modified rollback, however, it must be one of the versions described by de Nevers and Morris[12] or an equivalent. The reprint of the de Nevers and Morris paper appears as Appendix G of this Guideline.

4.4.2 Modeling in Areas Around Significant Point Sources

40 CFR 51.84 requires State implementation plans to contain a calculation of the maximum lead air quality concentrations and the location of those concentrations resulting from the following point sources for the demonstration of attainment:

--Primary lead smelters.

--Secondary lead smelters.

--Primary copper smelters.

--Lead gasoline additive plants.

--Lead-acid storage battery manufacturing plants that produce 1200 or more batteries per day.

--Any other stationary source that emits 25 or more tons per year of lead or lead compounds.

The regulation requires that a dispersion model be used for these analyses. The dispersion models that are acceptable are described in the section on point source models for sulfur dioxide and particulate matter in EPA's Guideline on Air Quality Models.[13]

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[12] de Nevers, Noel, and Roger Morris, Rollback Modeling--Basic and Modified. Paper no. 73-139, presented at the 66th Annual Meeting of the Air Pollution Control Association, Chicago, Illinois, June 24-28, 1973.

[13] Guideline on Air Quality Models. Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, N.C. EPA-450/2-78-027 (OAQPS No. 1.2-080). April, 1978.

These models do not account for deposition of large particles that may be generated by such sources, however. States that wish to account for such deposition may use the methods described in Appendices D and E of this Guideline. Appendix D is an exerpt from Meteorology and Atomic Energy,[14] and provides a description of a source depletion model. Appendix E is a reprint of an article in Atmospheric Environment,[15] and provides a description of a surface depletion model, which is computationally more complex than a source depletion model, but more accurate. The article provides comparisons of the two models. Persons interested in the surface depletion model are also directed to a further discussion on limitations of that model, which appeared in a later edition of Atmospheric Environment.[16]

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[14] Slade, David H. (ed.), Meteorology and Atomic Energy 1968. Prepared by Air Resources Laboratories, Research Laboratories, Environmental Science Services Administration, U.S. Department of Commerce, for the Division of Reactor Development and Technology, U.S. Atomic Energy Commission, Oak Ridge, Tennessee. July 1968. Pp. 202-208.

[15] Horst, Thomas W., "A Surface Depletion Model for Deposition from a Gaussian Plume." Atmospheric Environment, Vol. 11, pp. 41-46. 1977.

[16] Doran, J.C., and T.W. Horst, "Long-Range Travel of Airborne Material Subjected to Dry Deposition and a Surface Deposition Model for Deposition from a Gaussian Plume." Atmospheric Environment, Vol. 11, p. 1246. 1977.

5.0 AMBIENT LEAD MONITORING

5.1 INTRODUCTION

According to the requirements for State Implementation Plans (SIPs), two air quality lead monitors are required in each urbanized area (as defined by the U.S. Bureau of the Census)--

--that has a 1970 population greater than 500,000; or

--where lead air quality levels currently exceed or have exceeded 1.5 μg/m^3, quarterly arithmetic mean, measured since January 1, 1974. Lists of areas that meet these criteria appear in Tables 5.1 and 5.2. Table 5.2 is based only on limited data available to EPA, however. There are other data available to State and local air pollution control agencies that may indicate that other areas have concentrations in excess of 1.5 μg/m^3, quarterly arithmetic mean. In addition, EPA can require additional monitors in those areas and any other areas.

The monitoring networks operated by State and local agencies will consist of sites in three general categories: State and Local Air Monitoring Stations (SLAMS); National Air Monitoring Stations (NAMS), which are a subset of SLAMS; and Special Purpose Monitoring (SPM).

The strategy for State and local agencies to perform monitoring under these three categories was developed by the Standing Air Monitoring Work Group (SAMWG) and is more fully described in "Air Monitoring Strategy for State Implementation Plans," EPA-450/2-77-010, OAWM, OAQPS, RTP, N.C. June, 1977.

Although the SAMWG did not specifically address monitoring of ambient lead, the concepts developed by the SAMWG were incorporated into the requirements for State Implementation Plans (SIPs) for lead. The terminology of the SAMWG concerning the site categories (viz., SLAMS, NAMS, and

TABLE 5.1

URBANIZED AREAS* GREATER THAN 500,000 POPULATION
(1970 Census**)

AQCR#	AREA	AQCR#	AREA
043	New York, N.Y.-Northeastern New Jersey	106	New Orleans, La.
024	Los Angeles-Long Beach, Calif.	015	Phoenix, Ariz.
067	Chicago, Ill.-Northwestern Indiana	193	Portland, Ore.-Wash.
045	Philadelphia, Pa.-N.J.	244	San Juan, P.R.
123	Detroit, Mich.	080	Indianapolis, Ind.
030	San Francisco-Oakland, Calif.	120	Providence-Pawtucket-Warwick, R.I.-Mass.
119	Boston, Mass.	176	Columbus, Ohio
047	Washington, D.C.-Md.-Va.	217	San Antonio, Texas
174	Cleveland, Ohio	078	Louisville, Ky.-Ind.
070	St. Louis, Mo.-Ill.	173	Dayton, Ohio
197	Pittsburgh, Pa.	215	Fort Worth, Texas
131	Minneapolis-St. Paul, Minn.	223	Norfolk-Portsmouth, Va.
216	Houston, Texas	018	Memphis, Tenn.-Miss.
115	Baltimore, Md.	028	Sacramento, Calif.
215	Dallas, Texas	050	Ft. Lauderdale-Hollywood, Fla.
239	Milwaukee, Wisc.	160	Rochester, N.Y.
229	Seattle-Everett, Wash.	024	San Bernardino-Riverside, Calif.
050	Miami, Fla.	184	Oklahoma City, Okla.
029	San Diego, Calif.	004	Birmingham, Ala.
056	Atlanta, Ga.	174	Akron, Ohio
079	Cincinnati, Ohio-Ky.	049	Jacksonville, Fla.
094	Kansas City, Mo.	042	Springfield-Chicopee-Holyoke, Mass.-Conn.
162	Buffalo, N.Y.		

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*As defined in U.S. Bureau of the Census, "1970 Census Users' Guide;" U.S. Government Printing Office, Washington, D.C., 1970 (p. 82).

**U.S. Bureau of Census, "U.S. Census of Population: 1970; Number of Inhabitants; Final Report PC (1)-A1; United States Summary." U.S. Government Printing Office, Washington, D.C. 1971.

TABLE 5.2

URBANIZED AREAS WITH LEAD AIR CONCENTRATIONS EXCEEDING OR EQUAL TO 1.5 μg/m^3, MAXIMUM QUARTERLY MEAN (1975)

AQCR#	AREA
004	Birmingham, Ala.
005	Jackson, Miss.
015	Phoenix, Ariz.
031	Fresno, Calif.
024	Los Angeles--Long Beach, Calif.
028	Sacramento, Calif.
024	San Bernardino--Riverside, Calif.
029	San Diego, Calif.
030	San Francisco--Oakland, Calif.
030	San Jose, Calif.
036	Denver, Colo.
043	New York, N.Y.--Northeastern N.J.
042	Waterbury, Conn.
042	Springfield, Chicopee-Holyoke, Mass.--Conn.
045	Wilmington, Del.--N.J.
045	Philadelphia, Pa.--N.J.
047	Washington, D.C.--Md.--Va.
067	Chicago, Ill.--Northwestern Ind.
131	Minneapolis--St. Paul, Minn.
070	St. Louis, Mo.--Ill.
013	Las Vegas, Nev.
148	Reno, Nev.
184	Oklahoma City, Okla.
151	Scranton, Pa.
244	San Juan, P.R.
200	Columbia, S.C.
202	Greenville, S.C.
055	Chattanooga, Tenn.--Ga.
207	Knoxville, Tenn.
018	Memphis, Tenn.--Miss.
215	Dallas, Tex.
153	El Paso, Tex.
216	Houston, Tex.

Source: Data from EPA's Environmental Monitoring Support Laboratory, Statistical and Technical Analysis Branch.

SPM), does not appear in the lead SIP regulations, however, since that terminology has not yet been incorporated intc the monitoring requirements for SIPs for other pollutants. The terminology has been retained for the following discussion.

The basic approach of the strategy adopted by SAMWG is that the majority of State and local needs for monitoring data will be met with the SLAMS network. These needs include, for example, developing, tracking, and revising the control strategy of the SIPs; ensuring compliance with the national ambient air quality standards (NAAQS); measuring local air quality trends; determining potential ambient problems throughout urban areas; and understanding specific source impacts.

The primary national data needs are met through the use of NAMS, which are a subset of the SLAMS stations. The data from the NAMS stations are routinely reported to EPA Headquarters. These NAMS sites, usually two per major urbanized area, are selected to provide for national trends assessments and overall SIP progress and must also be standardized in terms of their operation, instrumentation, and placement as required by Section 319 of the Act.

The two primary objectives of stations in the NAMS network are (1) to monitor areas which are believed to experience the highest ambient concentrations for averaging times consistent with the NAAQS, and (2) to measure pollutant exposure to the public over the averaging time of the standard. Thus, the lead NAMS fall into two site categories: (1) stations located in the area of peak or maximum concentrations (middle scale), and (2) stations which combine poor air quality with high population density (neighborhood scale). Both stations are to avoid single point source influences to the extent possible since NAMS are for national trends and conditions. The SLAMS network could be used for single source problems since this network is designed primarily for local strategy development and trends.

Some SLAMS stations will also be located in areas experiencing highest ambient concentrations. The distinction is that NAMS will not be sited within exposure settings that are unique to certain urban areas. For example, NAMS will not be sited in confined street canyons since such exposure settings occur only in a relatively few urban areas.

From time to time, there are also data needs which would be impractical to meet with a routine network operation. These special needs are met with special purpose monitoring. Examples of these data needs include studying a specific source impact, evaluating why a particular site is not attaining a NAAQS, determining detailed spatial air quality gradients in a particular area, and validation of air quality models.

5.2 MONITORING SCALES

The monitor siting procedures which follow are required for SLAMS and NAMS monitoring. These procedures focus on the relationships between a monitoring objective and geographical location. The link between objective and location is made with the spatial scale of representativeness. The spatial scale of representativeness is defined as the area around a site which has reasonably homogeneous air quality. The goal in siting monitors is to match the scale most appropriate for the monitoring objective of a station to the spatial scale of the ambient air monitored at a particular location.

As a result, the spatial scale of representativeness is described in terms of the physical dimensions of the air near the station. The scales of most interest for lead monitoring include the following:

--Middle Scale--defines the concentration typical of areas up to several city blocks in size with dimensions ranging from about 100 meters to 0.5 kilometers.

--Neighborhood Scale--defines concentrations within some extended area of the city that has relatively uniform land use with dimensions in the 0.5 to 4.0 kilometer range.

These scales can be described by types of situations which frequently occur within an urban area. These situations are discussed below in terms of a physical description of a monitoring site measuring in one of the spatial scales of representativeness.

5.3 SITE DESCRIPTIONS

5.3.1 Roadway Site (Middle Scale)

The roadway site must be located adjacent to major roadways. These roadways may be arterials, freeways, expressways, or interstate highways with total average daily traffic (ADT) exceeding 50,000. If there is no roadway in the urbanized area with ADT exceeding 50,000, then the roadway with the largest traffic volume should be selected. The intent of this site is to obtain representative worst case measurements of lead where people may be reasonably expected to be exposed. In addition, it should be considered representative of concentrations in the area measured as well as similar areas within the urban area.

It should be recognized that in some situations, a roadway with a lower traffic volume may be better suited for the monitoring site because of the fact that people may reside, work, or play closer to the roadway. In these situations, the fact that population exposures occur closer to the roadway should override the traffic volume criterion for selecting the monitoring site. The site should be placed at least five meters but no greater than 15 meters from the closest traffic lane. It would be preferable to locate the site in an area where the roadway passes through areas where people reside or work. The monitor should be placed near residences and no greater than 5 meters above ground level.

Roadways that are at or below grade level should be selected in preference to elevated roadways where possible, since the differing heights of elevated roadways make representative long-term monitoring of high concentrations very difficult. This does not totally preclude monitoring near elevated roadways if the agency believes that population exposures are significant. Again, population exposure would override this siting consideration. The monitors must not be placed near areas such as toll gates or metered ramps since EPA has found[1] that the highest lead concentrations occur where traffic is moving at fairly high and constant rates of speed. In monitoring lead from roadways that are below grade, the monitors should be placed near the road but not actually in the cut section itself, since this would not be representative of population exposure.

5.3.2 Neighborhood Site (Neighborhood Scale)

This site must be located in an area of high traffic and population density but not necessarily near a major roadway. A minimum separation distance of 15 m between the monitor and the nearest roadway (over 2,000-3,000 vehicles per day) is recommended for purposes of data comparability. Areas at or near play areas or schools are good candidates for monitoring since children are the most susceptible members of the population at risk. It would also be desirable for monitors in this site category to be placed so that they measure the combined impact of mobile and stationary sources. The monitors must be placed as close to the ground level as practicable, but no greater than 5 meters above ground level, so that measurements will be taken as close to the breathing zone as practicable.

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[1] FY-77 Catalyst Research Project Report, Office of Research and Development, Environmental Protection Agency (under preparation).

5.3.3 Street Canyon Site (Middle Scale)

This type of SLAMS site should be located in an area of high traffic and population density. The site should be chosen to provide a measure of the influence of the immediate source on the pollution exposure of the population. These sites would typically be located in downtown areas in roadway corridors or canyons which have high traffic density (but not necessarily the largest traffic volume in the urbanized area) and relatively uniform and tall buildings lining both sides of the street. Monitors must be placed no higher than 5 meters above ground level.

5.4 OTHER CONSIDERATION FOR ALL SITES

If the sampler is located on a roof or other structure, then there should be a minimum of 2 meters separation from walls, parapets, penthouses, etc. The sampler should be placed at least 20 meters from trees since trees absorb particles as well as restrict air flow. The sampler (except street canyon sites) should also be located away from obstacles such as buildings, so that the distance between obstacles and the sampler are at least twice the height that the obstacle protrudes above the sampler. There should be unrestricted air flow in at least three out of the four major wind directions except for street canyon sites. One of the three should be the predominant direction for the season with the greatest pollution potential.

5.5 NETWORK DESIGN

Since the major objective of ambient lead monitoring by State and local agencies is to support the SIPs, the vast majority of monitoring sites should be located where the lead concentrations are expected to be the highest. Priority should be given to those locations which contain significant segments of the susceptible population at risk. The siting criteria discussed above are required only for NAMS and SLAMS type monitoring.

For NAMS, at least one of each of two types of sites are required to meet the objectives stated previously. These are the roadway site and the neighborhood site. It is believed that these two types of sites will provide data which will enable representative air quality characterizations on a national scale.

For additional SLAMS monitoring, SLAMS roadway sites do not need to meet any minimum traffic volume criterion (i.e., the 50,000 vehicle per day traffic criterion is not required). This is to allow State and local agencies to measure where significant air quality problems exist or to provide data for the development of spatial air quality gradients. The 50,000 VPD requirement was intended only for NAMS monitors so that, as a minimum, peak concentration measures would be obtained. The street canyon site is needed since many urban areas (primarily in the eastern part of the U.S.) have a significant portion of the inner city with street canyons. Therefore, for SLAMS purposes, this type of site may be required to allow for situations where segments of the population might be exposed to unhealthful levels of lead.

For SPM, the type of site used could be any of the ones used for SLAMS and NAMS. The site could be other than those discussed below because of the special nature or unique objective of the monitoring project.

5.6 FREQUENCY OF SAMPLING

The minimum acceptable sampling frequency for a quarterly average is once every six days. This is identical to the schedules currently required for total suspended particulate and ensures that each day of the week should appear at least twice in the 90-day sampling period, thereby reducing possible bias which may result from day-of-the-week variations. For a typically placed monitoring site with an average concentration near the standard, the true concentration could be expected to lie within ± 15 percent of the sample mean 95 percent of the time for a one-in-six-day sample. This is based on an observed coefficient of variation of 30 percent. The precision could be reduced to ± 10 percent of the sample mean 95 percent of the time for a one-in-three-day sample. This increase in precision, however, does not warrant the significant national costs of monitoring. Some areas, however, may have sufficient reasons to intensify their sampling frequency based upon local needs for data.

6.0 NEW SOURCE REVIEW

Procedures for the review of new stationary lead sources will be similar to those for sources of other pollutants. As explained in the preamble to the proposed regulations, EPA is developing regulations for new stationary sources of all pollutants. Procedures for performing review of new stationary sources appear in EPA's Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10: Procedures for Evaluating Air Quality Impact of New Stationary Sources.[1]

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[1] "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10: Procedures for Evaluating Air Quality Impact of New Stationary Sources." U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. OAQPS No. 1.2-029R, October, 1977.

7.0 DETERMINATION OF LEAD POINT SOURCE DEFINITION

Estimates of maximum quarterly lead air quality concentrations from several stationary source categories were made using the Single Source (CRSTER)[1] Model. The emission rates used in this analysis were taken from EPA's Background Support Document for Economic Impact Assessment of the Lead Ambient Air Quality Standard.[2] A summary of the modeling results is provided in Table 7-1.

An estimate of a lead point source definition was extracted from these data by using the following expression:

$$Q = \frac{S}{(\chi_p/Q_p)}$$

where: Q = the approximation to the point source definition (t/y);

S = the assumed NAAQS for lead ($\mu g/m^3$);

χ_p = the maximum quarterly concentration ($\mu g/m^3$); and

Q_p = the lead emission rate (t/y).

This equation yields the emission rate above which the standard is violated.

The results of this calculation for all the sources appear in Table 7-1. The lowest point source definition for a standard of 1.5 $\mu g/m^3$ quarterly arithmetic mean, is 2 tons/year, based on the estimated impact from hypothetical grey iron foundries and ferroalloy plants.

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[1] User's Manual for Single Source (CRSTER) Model. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. EPA-450/2-77-013. July 1977.

[2] Background Support Document for Economic Impact Assessment of the Lead Ambient Air Quality Standard. U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards. January 12, 1978.

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TABLE 7-1: STATIONARY SOURCE QUARTERLY MODELING RESULTS AND POINT SOURCE DEFINITION FOR NAAQS QUARTERLY AVERAGE OF 1.5 μg/m^3

Industry Type	Q_p Lead Emission Rate (t/yr)	χ_p Maximum Quarterly Concentration (μg/m^3)	χ_p/Q_p $\left(\frac{\mu g/m^3}{t/yr}\right)$	Point Source* Definition (t/yr)
Primary Lead	110	2.5	0.023	65
Primary Copper	94	2.6	0.028	54
Tetraethyl Lead Mfg.	243	12.5	0.051	29
Secondary Lead	63	15	0.24	6
Grey Iron	2.1	1.5	0.71	2
Ferroalloy	0.28	0.24	0.86	2
Battery Manufacture (500 BPD) w/o PbO production	1.6	0.6	0.38	4
Battery Manufacture (6500 BPD) w/PbO production	23	4.8	0.21	7

*Emission rates above which the NAAQS will be violated.

The predominant cause of the elevated concentrations from these two facilities was assumed to be fugitive emissions. The emission factors used to estimate the fugitive emissions from these facilities were derived indirectly from ambient particulate data and assumptions concerning lead content of the particulate matter. Thus, they are of questionable validity. The point source definition will only be used in two functions: emission inventory development and possibly new source review. A slightly larger point source definition would not unduly affect the accuracy of the control strategy analysis or the number of sources that would have to be reviewed under the new source review requirements (which will not be included in the lead implementation plan regulations but will appear in a subsequent rulemaking). Because of this and the uncertainties in the emission factors, and because State resources for gathering lead emission data are severely limited, it appears that a less stringent point source definition of 5 tons/year is warranted.

APPENDIX A

PROCEDURES FOR DETERMINING THE INORGANIC LEAD EMISSIONS FROM STATIONARY SOURCES

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PROCEDURES FOR DETERMINING THE INORGANIC LEAD EMISSIONS FROM STATIONARY SOURCES

ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

MARCH 1978

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PROCEDURE FOR DETERMINING THE INORGANIC LEAD EMISSIONS FROM STATIONARY SOURCES

1. Principle and Applicability

1.1 Principle. Particulate and gaseous lead emissions are withdrawn isokinetically from the source. The collected samples are digested in acid solution and analyzed by atomic absorption spectrometry using an air acetylene flame.

1.2 Applicability. This method is applicable for the determination of inorganic lead emissions from stationary sources.

2. Range, Sensitivity, Precision, and Interferences

2.1 Range. The upper limit can be considerably extended by dilution. For a minimum analysis accuracy of ± 10%, a minimum lead mass of 100 μg should be collected.

2.2 Analytical Sensitivity. Typical sensitivity for a 1% change in absorption (0.0044 absorbance units) are 0.2 and 0.5 μg Pb ml^{-1} for the 217.0 and 283.3 nm lines, respectively.

2.3 Precision. The within-laboratory precision, as measured by the coefficient of variation, was determined at a gray iron foundry, a lead storage battery manufacturing plant, a secondary lead smelter, and a lead recovery furnace at an alkyl lead manufacturing plant. The concentrations encountered during these tests ranged from 0.61 to 123.3 mg Pb m^{-3}. The coefficient of variation for each run, which is the standard deviation of the run expressed as a percentage of the run mean concentration, ranged from 0.2 to 9.5%.

2.4 Interferences. Sample matrix effects may interfere with the analysis for lead by flame atomic absorption. If the analyst suspects that the sample matrix is causing erroneous results, the presence of these matrix effects can be confirmed and frequently corrected for by carrying out the analysis using the Method of Standard Additions.

High concentrations of copper may interfere with the analysis of lead at 217.0 nm. This interference can be avoided by analyzing the samples for lead using the 283.3 nm lead line.

3. Apparatus

3.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure A-1. Complete construction details are given in APTD-0581; commercial models of this train are also available. For changes from APTD-0581 and for allowable modifications of the train shown in Figure A-1, see the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576. Since correct usage is important in obtaining valid results, all users should read APTD-0576 and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. The sampling train consists of the following components:

3.1.1 Probe Nozzle. Stainless steel (316) or glass with sharp, tapered leading edge. The angle of taper shall be $\leq 30^{\circ}$, and the taper shall be on the outside to preserve a constant internal diameter. The probe nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing; other materials of construction may be used, subject to the approval of the Administrator.

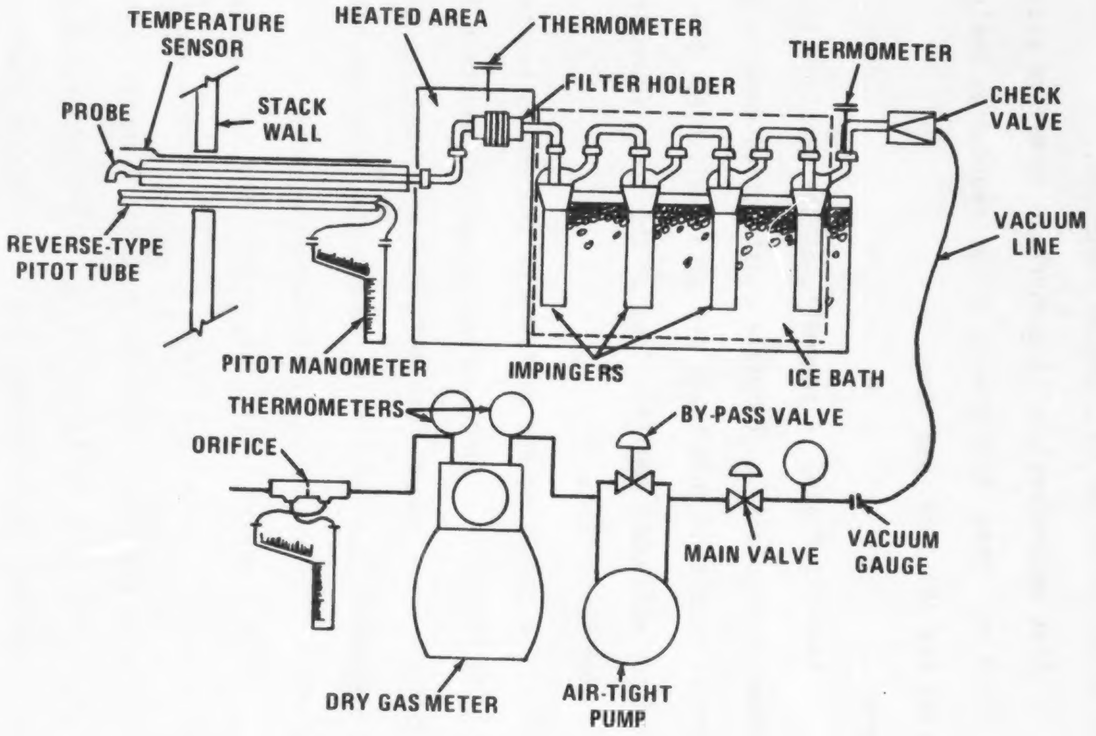

Figure A-1. Inorganic lead sampling train.

A range of nozzle sizes suitable for isokinetic sampling should be available, e.g., 0.32 to 1.27 cm (1/8 to 1/2 in.), or larger if higher volume sampling trains are used, inside diameter (I.D.) nozzles in increments of 0.16 cm (1/16 in.). Each nozzle shall be identified and calibrated (see Section 5.2).

3.1.2 Probe Liner. Borosilicate or quartz glass tubing with a heating system capable of maintaining a gas temperature at the exit end during sampling of 120° ± 14°C (248° + 25°F); note that lower exit temperatures are acceptable, provided that they exceed the stack gas dew point. Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the procedure outlined in APTD-0576) will be considered acceptable.

Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480°C (900°F); quartz liners shall be used for temperatures between 480° and 900°C (900° and 1650°F). Both types of liners may be used at temperatures higher than specified for short periods of time, subject to the approval of the Administrator. The softening temperature for borosilicate is 820°C (1508°F), and for quartz it is 1500°C (2732°F).

Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners. Alternatively, metal liners (e.g., 316 stainless steel, Incoloy 825*, or other corrosion resistant metals) made of stainless tubing be used, subject to the approval of the Administrator.

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*Mention of trade names or specific products does not constitute endorsement by the U.S. Environmental Protection Agency.

3.1.3 Pitot Tube. Type S, as described in Section 2.1 of Method 2, 40 CFR 60 Appendix A, or other device approved by the Administrator. The Pitot tube shall be attached to the probe (as shown in Figure A-1) to allow constant monitoring of the stack gas velocity. The impact (high pressure) opening plane of the Pitot tube shall be even with or above the nozzle entry plane (see Method 2, Figure 2-6b) during sampling. The Type S Pitot tube assembly shall have a known coefficient, determined as outlined in Section 4 of Method 2.

3.1.4 Differential Pressure Gauge. Inclined manometer or equivalent device (two), as described in Section 2.2 of Method 2. One manometer shall be used for velocity head (Δp) readings, and the other, for orifice differential pressure readings.

3.1.5 Filter Heating System. Any heating system capable of maintaining a temperature around the filter holder during sampling of 120° ± 14°C (248° ± 25°F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. Alternatively, the tester may opt to operate the equipment at a temperature lower than that specified. A temperature gauge capable of measuring temperature to within 3°C (5.4°F) shall be installed so that the temperature around the filter holder can be regulated and monitored during sampling. Heating systems other than the one shown in APTD-0581 may be used.

3.1.6 Filter Holder. Borosilicate glass, with a glass frit filter support and a silicone rubber gasket. Other materials of construction (e.g., stainless steel, Teflon, Viton) may be used, subject to the approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The filter holder shall be attached immediately at the outlet of the probe.

3.1.7 Impingers. Four impingers connected in series with leak-free ground glass fittings or any similar leak-free noncontaminating fittings. The first, third, and fourth impingers shall be of Greenburg-Smith design, modified by replacing the tip with a 1.3 cm (1/2 in.) I.D. glass tube extending to about 1.3 cm (1/2 in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. The first and second impingers shall contain known quantities of 0.1 N HNO_3 (Section 4.1.3), the third shall be empty, and the fourth shall contain a known weight of silica gel or equivalent desiccant. A thermometer, capable of measuring temperature to within 1°C (2°F), shall be placed at the outlet of the fourth impinger for monitoring purposes.

3.1.8 Metering System. Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3°C (5.4°F), dry gas meter capable of measuring volume to within 2%, and related equipment, as shown in Figure A-1. Other metering systems capable of maintaining sampling rates within 10% of isokinetic and of determining sample volumes to within 2% may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a Pitot tube, the system shall enable checks of isokinetic rates.

Sampling trains utilizing metering systems designed for flow rates higher than that described in APTD-0581 or APTD-0576 may be used provided that the specifications of this method are met.

3.1.9 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby National Weather Service station, in which case the station value (which is the absolute barometric pressure) shall be requested, and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

3.1.10 Gas Density Determination Equipment. Temperature sensor and pressure gauge, as described in Sections 2.3 and 2.4 of Method 2, and gas analyzer, if necessary, as described in Method 3 (40 CFR 60 Appendix A). The temperature sensor shall, preferably, be permanently attached to the Pitot tube or sampling probe in a fixed configuration, such that the tip of the sensor extends beyond the leading edge of the probe sheath and does not touch any metal. Alternatively, the sensor may be attached just prior to use in the field. Note, however, that if the temperature sensor is attached in the field, the sensor must be placed in an interference-free arrangement with respect to the Type S Pitot tube openings (see Method 2, Figure 2-7). As a second alternative, provided that a difference of not more than 1% in the average velocity measurement is introduced, the temperature gauge need not be attached to the probe or Pitot tube. (This alternative is subject to the approval of the Administrator.)

3.2 Sample Recovery. The following items are needed:

3.2.1 Probe-Liner and Probe-Nozzle Brushes. Nylon bristle brushes with stainless steel wire handles. The probe brush shall have extensions (at least as long as the probe) of stainless steel, Nylon, Teflon, or similarly inert material. The brushes shall be properly sized and shaped to brush out the probe liner and nozzle.

3.2.2 Glass Wash Bottles--Two.

3.2.3 Glass Sample Storage Containers. Chemically resistant, borosilicate glass bottles, for 0.1 N HNO_3 impinger and probe solutions and washes, 1000 ml. Screw cap liners shall be either rubber-backed Teflon or constructed so as to be leak-free and resistant to chemical attack by 0.1 N HNO_3. (Narrow mouth glass bottles have been found to be less prone to leakage.)

3.2.4 Petri Dishes. For filter samples, glass or polyethylene, unless otherwise specified by the Administrator.

3.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 2 ml or 1 g. The graduated cylinder shall have a minimum capacity of 500 ml, and subdivisions no greater than 5 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less.

3.2.6 Plastic Storage Containers. Air-tight containers to store silica gel.

3.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

3.2.8 Funnel. Glass, to aid in sample recovery.

3.3 Analysis.

3.3.1 Atomic Absorption Spectrophotometer. With lead hollow cathode lamp and burner for air/acetylene flame.

3.3.2 Hot Plate.

3.3.3 Erlenmeyer Flasks. 125 ml 24/40 ₮.

3.3.4 Membrane Filters. Millipore SCWPO 4700 or equivalent.

3.3.5 Filtering Apparatus. Millipore vacuum filtration unit, or equivalent, for use with the above membrane filter.

3.3.6 Volumetric Flasks. 100 ml, 250 ml.

4. Reagents

4.1 Sampling.

4.1.1 Filters. High purity glass fiber filters, without organic binder, exhibiting at least 99.95% efficiency ($\leq$ 0.05% penetration) on 0.3

micron dioctyl phthalate smoke particles. The filter efficiency test shall be conducted in accordance with ASTM Standard Method D 2986-71. Test data from the supplier's quality control program are sufficient for this purpose. Filters shall be Gelman Spectro Grade, or equivalent, with lot assay for Pb. Reeve Angel 934 AH and MSA 1106 BH filters have been found to be equivalent.

4.1.2 Silica Gel. Indicating type, 6 to 16 mesh. If previously used, dry at 175°C (350°F) for 2-hr. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

4.1.3 Nitric Acid, 0.1 N. Prepared from reagent grade HNO_3 and deionized, distilled water (Reagent 4.4.1, below). It may be desirable to run blanks prior to field use to eliminate a high blank on test samples. Prepare by diluting 6.5 ml of concentrated HNO_3 (69%) to 1 liter with deionized, distilled water.

4.1.4 Crushed Ice.

4.1.5 Stopcock Grease. HNO_3 insoluble, heat stable, silicone grease. This is not necessary if screw-on connectors with Teflon sleeves, or similar, are used. Alternatively, other types of stopcock grease may be used, subject to the approval of the Administrator.

4.2 Pretest Preparation.

4.2.1 Nitric Acid, 6 N. Prepared from reagent grade HNO_3 and deionized, distilled water. Prepare by diluting 390 ml of concentrated HNO_3 (69%) to 1 liter with deionized, distilled water.

4.3 Sample Recovery.

4.3.1 Nitric Acid, 0.1 N. Same as 4.1.3 above.

4.4 Analysis.

4.4.1 Water. Deionized, distilled to conform to ASTM Specification D 1193-74, Type 3.

4.4.2 Nitric Acid. Concentrated ACS reagent grade, or equivalent.

4.4.3 Nitric Acid, 50% (V/V). Dilute 500 ml of concentrated HNO_3 to 1 liter with deionized, distilled water.

4.4.4 Stock Lead Standard Solution (1000 μg Pb ml^{-1}). Dissolve 0.1598 g of reagent grade $Pb\ (NO_3)_2$ in about 60 ml of deionized distilled water, add 2 ml concentrated HNO_3, and dilute to 100 ml with dionized, distilled water.

4.4.5 Lead Standards.

4.4.5.1 Solution Sample Standards. Pipet 0.0, 1.0, 2.0, 3.0, 4.0, and 5.0 ml aliquots of the stock lead standard solution (Reagent 4.4.4) into 250 ml volumetric flasks. Add 5 ml concentrated HNO_3 to each flask and dilute to volume with deionized, distilled water. These working standards contain 0.0, 4.0, 8.0, 12.0, 16.0, and 20.0 μg Pb ml^{-1}, respectively. Additional standards at other concentrations should be prepared in a similar manner as needed.

4.4.6 Air. Of a quality suitable for atomic absorption analysis.

4.4.7 Acetylene. Of a quality suitable for atomic absorption analysis.

4.4.8 Hydrogen peroxide. ACS reagent grade or equivalent, 3% by volume.

5. Procedure

5.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

5.1.1 Pretest Preparation. All the components shall be maintained and calibrated according to the procedure described in APTD-0576, unless otherwise specified herein. In addition, prior to testing, all sample-exposed surfaces shall be rinsed, first with 6 N HNO_3 then with deionized, distilled water.

Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel need not be preweighed, but may be weighed directly in its impinger just prior to train assembly.

Check filters visually against light for irregularities and flaws or pinhole leaks. Label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and analysis.

5.1.2 Preliminary Determinations. Select the sampling site and the minimum number of sampling points according to Reference Method 1 or as specified by the Administrator. Determine the stack pressure, temperature, and the range of velocity heads using Reference Method 2; it is recommended that a leak-check of the pitot lines (see Method 2, Section 3.1) be performed. Determine the moisture content using Reference Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight as described in Reference Method 3.

Select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not change the nozzle size. Insure that the proper differential pressure gauge is chosen for the range of velocity heads encountered (see Section 2.2 of Method 2).

Select a suitable probe liner and probe length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probes.

Select a total sampling time such that (1) the sampling time per point is not less than 2 min. (or greater time interval as specified by the Administrator), and (2) a minimum lead mass of 100 μg is collected in the sample. The sampling time and volume will therefore vary from source-to-source.

It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors.

In some circumstances, e.g., batch cycles, it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

5.1.3 Preparation of Collection Train. During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

Place 100 ml of 0.1 HNO_3 in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 μg of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to insure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

Using tweezers or clean disposable surgical gloves, place a filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed, so as to prevent the sample gas stream from circumventing the filter. Check the filter for tears after assembly is completed.

When glass liners are used, install the selected nozzle using a Viton A O-ring when stack temperatures are less than 260°C (500°F) and an asbestos string gasket when temperatures are higher. See APTD-0576 for details. Other connecting systems using either 316 stainless steel or Teflon ferrules may be used. When metal liners are used, install the nozzle as above or by a leak-free direct mechanical connection. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

Set up the train as in Figure A-1, using (if necessary) a very light coat of silicone grease on all ground glass joints, greasing only the outer portion (see APTD-0576) to avoid possibility of contamination by the silicone grease.

Place crushed ice around the impingers.

5.1.4 Leak-Check Procedures.

5.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak-check, the following procedure shall be used.

After the sampling train has been assembled, turn on and set the filter and probe heating systems at the desired operating temperature. Allow time for the temperature to stabilize. If a Viton A O-ring or other leak-free connection is used in assembling the probe nozzle to the probe liner, leak-check the train at the sampling site by plugging the nozzle and pulling a 380 mm Hg (15 in. Hg) vacuum.

Note: A lower vacuum may be used, provided that it is not exceeded during the test.

If an asbestos string is used, do not connect the probe to the train during the leak-check. Instead, leak-check the train by first plugging the inlet to the filter and pulling a 380 mm Hg (15 in. Hg) vacuum (see note immediately above). Then connect the probe to the train and leak-check at about 25 mm Hg (1 in. Hg) vacuum; alternatively, the probe may be leak-checked with the rest of the sampling train, in one step, at 380 mm Hg (15 in. Hg) vacuum. Leakage in excess of 4% of the average sampling rate or 0.00057 m^3/min (0.02 ft^3 min^{-1}), whichever is less, are unacceptable.

The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. Start the pump with bypass valve fully open and coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of bypass valve; this will cause 0.1 N HNO_3 to back up into the filter. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak check as shown below and start over.

When the leak-check is completed, first slowly remove the plug from the inlet to the probe and immediately turn off the vacuum pump. This prevents the 0.1N HNO_3 in the impingers from being forced backward and silica gel from being entrained backward.

5.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes necessary, a leak-check shall be conducted immediately before the change is made. The leak-check shall be done according to the procedure outlined in Section 5.1.4.1 above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 m^3/min (0.02 ft^3 min^{-1}) or 4% of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered; if, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and plan to correct the sample volume as shown in Section 6.3 of Reference Method 5, or shall void the sampling run.

Immediately after component changes, leak-checks are optional; if such leak-checks are done, the procedure outlined in Section 5.1.4.1 above shall be used.

5.1.4.3 Posttest Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leak-check shall be done in accordance with the procedures outlined in Section 5.1.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.00057 m^3/min (0.02 ft^3) or 4% of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered. However, if a higher leakage rate is obtained, the tester shall either record the leakage rate and correct the sample volume as shown in Section 6.3 of Method 5, or shall void the sampling run.

5.1.5 Sampling Train Operation. During the sampling run, maintain an isokinetic sampling rate (within 10% of true isokinetic unless otherwise specified by the Administrator).

For each run, record the data required on a data sheet such as the one shown in EPA Method 5, Figure 5-2. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak-check, and when sampling is halted. Take other readings required by Figure 5-2 of Method 5 at least once at each sample point during each time increment and additional readings when significant changes (20% variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Clean the portholes prior to the test run to minimize the chance of sampling deposited material. To begin sampling, remove the nozzle cap, verify that the filter and probe are at proper temperature, and that the Pitot tube and probe are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Nomographs are available, which aid in the rapid adjustment of the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S Pitot tube coefficient is 0.85 ± 0.02, and the stack gas equivalent density (dry molecular weight) is equal to 29 ± 4. APTD-0576 details the procedure for using the nomographs. If C_p and M_d are outside the above stated ranges, do not use the nomographs unless appropriate steps (Shigehara, 1974) are taken to compensate for the deviations.

When the stack is under significant negative pressure ($\geq$ a water column the height of the impinger stem), take care to close the coarse adjust valve before inserting the probe into the stack to prevent 0.1 N HNO_3 from backing into the filter. If necessary, the pump may be turned on with the coarse adjust valve closed.

When the probe is in position, block off the openings around the probe and porthole to prevent dilution of the gas stream.

Traverse the stack cross-section, as required by Reference Method 1 or as specified by the Administrator, without bumping the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes.

During the test run, add ice and, if necessary, salt to the ice bath, to maintain a temperature of less than 20°C (68°F) at the impinger/silica gel outlet. Also, periodically check the level and zero of the manometer.

A single train shall be used for the entire sample run, except in cases where simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or, in cases where equipment failure necessitates a change of trains. In all other situations, the use of two or more trains will be subject to the approval of the Administrator.

Note that when two or more trains are used, separate analyses of the sample fractions from each train shall be performed, unless otherwise specified by the Administrator. Consult with the Administrator for details concerning the calculation of results when two or more trains are used.

At the end of the sample run, turn off the coarse adjust valve, remove the probe and nozzle from the stack, turn off the pump, record the final dry gas meter reading, and conduct a post-test leak-check, as outlined in Section 5.1.4.3. Also, leak-check the Pitot lines as described in Method 2, Section 3.1; the lines must pass this leak-check in order to validate the velocity head data.

5.1.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Section 6.11 of Method 5) to determine whether the run was valid or another test run should be made. If there was difficulty in maintaining isokinetic rates due to source conditions, consult with the Administrator for possible variance on the isokinetic rates.

5.2 Sample Recovery. Proper cleanup procedure begins as soon as the probe is removed from the stack at the end of the sampling period. Allow the probe to cool.

When the probe can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it. Do not cap off the probe tip tightly while the sampling train is cooling down as this would create a vacuum in the filter holder, thus drawing liquid from the impingers into the filter.

Before moving the sample train to the cleanup site, remove the probe from the sample train, wipe off the silicone grease, and cap the open outlet of the probe. Be careful not to lose any condensate that might be present. Wipe off the silicone grease from the glassware inlet where the probe was fastened and cap the inlet. Remove the umbilical cord from the last impinger and cap the impinger. Either ground-glass stoppers, plastic caps, or serum caps may be used to close these openings.

Transfer the probe and filter-impinger assembly to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

Save a portion of the 0.1N HNO_3 used for sampling and cleanup as a blank. Place 200 ml of this 0.1N HNO_3 taken directly from the bottle being used into a glass sample container labeled "0.1N HNO_3 blank."

Inspect the train prior to and during disassembly and note any abnormal conditions. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the filter holder and place it in its identified petri dish container. If it is necessary to fold the filter, do so such that the sample-exposed side is inside the fold. Carefully transfer to the petri dish any visible sample matter and/or filter fibers that adhere to the filter holder gasket by using a dry Nylon bristle brush and/or a sharp-edged blade. Seal the container.

Container No. 2. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover sample matter or any condensate from the probe nozzle, probe fitting, probe liner, and front half of the filter holder by washing these components with 0.1 N HNO_3 and placing the wash into a glass or polyethylene container. Measure and record (to the nearest ml) the total amount of 0.1N HNO_3 used for each rinse. Perform the 0.1N HNO_3 rinses as follows:

Carefully remove the probe nozzle and clean the inside surface by rinsing with 0.1N HNO_3 from a wash bottle while brushing with a stainless steel, Nylon-bristle brush. Brush until the 0.1N HNO_3 rinse shows no visible particles, then make a final rinse of the inside surface with 0.1N HNO_3.

Brush and rinse with 0.1N HNO_3 the inside parts of the Swagelok fitting in a similar way until no visible particles remain.

Rinse the probe liner with 0.1N HNO_3 by tilting the probe and squirting 0.1N HNO_3 into its upper end, while rotating the probe so that all inside surfaces will be rinsed with 0.1N HNO_3. Let the 0.1N HNO_3 drain from the lower end into the sample container. A glass funnel may be used to aid in transferring liquid washes to the container. Follow the 0.1N HNO_3 rinse with a probe brush. Hold the probe in an inclined position, squirt 0.1N HNO_3 into the upper end of the probe as the probe brush is being pushed with a twisting action through the probe; hold a sample container underneath the lower end of the probe and catch any 0.1N HNO_3 and sample matter that is brushed from the probe. Run the brush through the probe three times or more until no visible sample matter is carried out with the 0.1N HNO_3 and none remains on the probe liner on visual inspection. With stainless steel or other metal probes, run the brush through in the above prescribed manner at least six times, since metal probes have small crevices in which sample matter can be entrapped. Rinse the brush with 0.1N HNO_3 and quantitatively collect these washings in the sample container. After the brushing make a final 0.1N HNO_3 rinse of the probe as described above.

It is recommended that two people be used to clean the probe to minimize loss of sample. Between sampling runs, keep brushes clean and protected from contamination.

After insuring that all joints are wiped clean of silicone grease, clean the inside of the front half of the filter holder by rubbing the surfaces with a Nylon bristle brush and rinsing with 0.1N HNO_3. Rinse each surface three times or more, if needed, to remove visible sample matter. Make a final rinse of the brush and filter holder. After all 0.1 N HNO_3 washings and sample matter are collected in the sample container, tighten the lid on the sample container so that 0.1N HNO_3 will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to determine whether leakage occurred during transport. Label the container to clearly identify its contents.

Container No. 3. Check the color of the indicating silica gel to determine if it has been completely spent and make a notation of its condition. Transfer the silica gel from the fourth impinger to the original container and seal. A funnel may make it easier to pour the silica gel without spilling. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of dust particles that may adhere to the walls and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available in the field, follow the procedure for Container No. 3 under "Analysis."

Container No. 4. Due to the large quantity of liquid involved, the impinger solutions are placed together in a separate container. However, they may be combined with the contents of Container No. 2 at the time of analysis in order to reduce the number of analyses required. Clean each of the first three impingers and connecting glassware in the following manner:

1. Wipe the impinger ball joints free of silicone grease and cap the joints.

2. Rotate and agitate each impinger, so that the impinger contents might serve as a rinse solution.

3. Transfer the contents of the impingers to a 500 ml graduated cylinder. The outlet ball joint cap should be removed and the contents drained through this opening. The impinger parts (inner and outer tubes) must not be separated while transferring their contents to the cylinder.

Measure the liquid volume to within ± 1 ml. Alternatively, determine the weight of the liquid to within ± 0.5 g by using a balance. The volume or weight of liquid present, along with a notation of any color or film observed in the impinger catch, is recorded in the log. This information is needed, along with the silica gel data, to calculate the stack gas moisture content (see Method 5, Figure 5-3).

4. Transfer the contents of the first three impingers to Container No. 4.

5. Pour approximately 30 ml of 0.1N HNO_3 into each of the first three impingers and agitate the impingers. Drain the 0.1N HNO_3 through the outlet arm of each impinger into the No. 4 sample container. Repeat this operation a second time; inspect the impingers for any abnormal conditions.

6. Wipe the ball joints of the glassware connecting the impingers free

of silicone grease and rinse each piece of glassware twice with 0.1N HNO_3; this rinse is collected in Container No. 4. (Do not rinse or brush the glass-fritted filter support.)

Mark the height of the fluid level to determine whether leakage occurred during transport. Label the container to clearly identify its contents.

Note: In steps 5 and 6 above, the total amount of 0.1N HNO_3 used for rinsing must be measured and recorded.

5.3 Analysis

5.3.1 Container No. 3. This step may be conducted in the field. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance.

5.3.2 Lead Sample Preparation and Analysis

5.3.2.1 Container No. 1. Cut the filter into strips and transfer the strips and all loose particulate matter into 125-ml Ehrlenmeyer Flask. Rinse the petri dish with 10 ml of 50% nitric acid to insure a quantitative transfer and add to the flask. (Note: if the total volume required in Section 5.3.2.3 will exceed 80 ml, it will be necessary to use a 250-ml Ehrlenmeyer flask in place of the 125-ml Ehrlenmeyer flask.)

5.3.2.2. Containers No. 2 and No. 4. Combine the contents of Containers No. 2 and No. 4 and take to dryness on a hot plate. (Note: Prior to analysis, the liquid level in Containers No. 2 and/or No. 4 should be checked; confirmation as to whether or not leakage occurred during transport should be made on the analysis sheet. If a noticeable amount of leakage has occurred, either void the sample or take steps, subject to the approval of the Administrator, to correct the final results.)

5.3.2.3 Sample Extraction for Lead. Based on the approximate stack gas particulate concentration and the total volume of stack gas sampled, estimate the total weight of sample collected. Now transfer the residue from Containers No. 2 and No. 4 to the 125-ml Ehrlenmeyer flask that contains the filter using a rubber policeman and 10 ml of 50% (V/V) HNO_3 for every 100 μg of sample collected in the train or a minimum of 30 ml of 50% HNO_3, whichever is larger.

Place the Ehrlenmeyer flask on a hot plate and heat with periodic stirring for 30 min. at a temperature just below boiling. If the sample volume falls below 15 ml, add more nitric acid. Add 10 ml of 3% H_2O_2 and continue heating for 10 min. Add 50 ml of hot (80°C) distilled deionized water and heat for 20 min. Remove flask from heat and allow to cool. Filter the sample through a Millipore membrane filter or equivalent and transfer the filtrate to a 250-ml volumetric flask. Dilute to volume using distilled, deionized water.

5.3.2.4 Filter Blank. Determine a filter blank using two filters from each lot of filters used in the sampling train. Cut each filter into strips and place each filter in a separate 125-ml Ehrlenmeyer flask. Add 15 ml of 50% (V/V) HNO_3 and treat as described in Section 5.3.2.3 (Extraction for Lead)using 10 ml of 3% H_2O_2 and 50 ml of hot, distilled, deionized water. Filter and dilute to a total volume of 100 ml using distilled, deionized water.

5.3.2.5 0.1 N Nitric Acid Blank. Take the entire 200 ml of 0.1 N HNO_3 to dryness on a steam bath, add 15 ml of 50% (V/V) HNO_3, and treat as described in Section 5.3.2.3 (Extraction of Lead) using 10 ml of 3% H_2O_2 and 50 ml of hot, distilled, deionized water. Dilute to a total volume of 100 ml using distilled, deionized water.

5.3.2.6 Lead Determination. Calibrate the spectrophotometer as described in Section 6.1 and determine the absorbance for each source sample, the filter blank and 0.1N HNO_3 blank. Analyze each sample three times in this manner

Make appropriate dilutions, as required, to bring all sample lead concentrations into the linear absorbance range of the spectrophotometer.

If the lead concentration of a sample is at the low end of the calibration curve and high accuracy is required, the sample can be taken to dryness on a hot plate and the residue dissolved in the appropriate volume of water to bring it into the optimum range of the calibration curve.

5.3.2.7 Mandatory Check for Matrix Effects on the Lead Results. The analysis for lead by atomic absorption is sensitive to the chemical composition and to the physical properties (viscosity, pH) of the sample (matrix effects). Since the lead procedure described here will be applied to many different sources, it can be anticipated that many different sample matrices will be encountered. Thus, it is mandatory that at least one sample from each source be checked using the Method of Additions to ascertain that the chemical composition and physical properties of the sample did not cause erroneous analytical results.

Three acceptable "Method of Additions" procedures are described in the General Procedure Section of the Perkin Elmer Corporation Manual. If the results of the Method of Additions procedure on the source sample do not agree within 5% of the value obtained by the conventional atomic absorption analysis, then all samples from the source must be reanalyzed using the Method of Additions procedure.

6. Calibration

Maintain a laboratory log of all calibrations.

6.1 Sampling Train Calibration. Calibrate the sampling train components according to the indicated sections of Method 5 (40 CFR 60 Appendix A): probe nozzle (Section 5.1); Pitot tube assemble (Section 5.2); metering system

(Section 5.3); probe heater (Section 5.4); temperature gauges (Section 5.5); barometer (Section 5.7). Note that the leak-check of the metering system (Section 5.6 of Method 5) applies to this method.

6.2 Spectrophotometer. Measure the absorbance of the standard solutions using the instrument settings recommended by the spectrophotometer manufacturer. Repeat until good agreement is obtained between replicates. Plot the absorbance (y-axis) versus concentration in μg Pb ml^{-1} (x-axis). Draw or compute a straight line through the linear portion of the curve. Do not force the calibration curve through zero, but if the curve does not pass through the origin or at least lie closer to the origin than ± 0.003 absorbance units, check for incorrectly prepared standards and for curvature in the calibration curve.

To determine stability of the calibration curve, run a blank and a standard after every five samples and recalibrate, as necessary.

7. Calibrations

7.1 Nomenclature.

A_s = Stack area, m^2

$(Pb)_o$ = Total μg of lead in the source samples after correcting for all dilutions.

P_{bar} = Barometric pressure at the sampling site, mm Hg.

P_s = Absolute stack gas pressure, mm Hg.

R = Rate of lead emission, g/day.

T_m = Absolute average dry gas meter temperature, K.

T_s = Absolute stack temperature, K.

v_s = Average stack gas velocity, m/sec.

V_m = Total volume of gas sample as measured by the dry gas meter, corrected for leakage, m^3.

V_{total} = Total gas sample volume (stack conditions), m^3.

Y = Dry gas meter calibration factor.

ΔH = Average pressure differential across the orifice meter, mm H_2O.

7.2 Calculate V_m, the total volume of dry gas metered (corrected for leakage, if necessary, as outlined in Section 6.3 of Method 5, 40 CFR 60, Appendix A).

7.3 Calculate the volume of water vapor and the moisture content of the stack gas, from data obtained in this testing, use Equations (5.2) and (5.3) of Method 5, 40 CFR 60, Appendix A.

7.4 Calculate, v_s, the average stack gas velocity, using Equation (2-9) of Method 2, 40 CFR 60, Appendix A; use velocity head (ΔP), temperature, pressure, and moisture data from this field test.

7.5 Calculate the total gas sample volume at stack conditions, using the following equation:

$$V_{total} = V_m \, Y \left[\frac{T_s}{T_m} \right] \left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_s} \right] \qquad \text{(A-1)}$$

7.6 Total Lead in Source Sample. For each source sample correct the average absorbance for the contribution of the filter blank and the 0.1 N HNO_3 blank. Use the calibration curve and this corrected absorbance to determine the lead concentration in the sample aspirated into the spectrophotometer.

Calculate the total lead content in the original source sample $(Pb)_o$; correcting for all the dilutions that were made to bring the lead concentration of the sample into the linear range of the spectrophotometer.

7.7 Total Lead Emission. Calculate the total amount of lead emitted from each stack per day by Equation (A-2). This equation is applicable for continuous operations. For cyclic operations, use only the time per day each stack is in operation The total lead emissions from a source will be the summation of results from all stacks.

$$R = \left[\frac{(Pb)_o \; v_s \; \rho_s}{V_{total}}\right] \left[\frac{86400 \text{ seconds/day}}{10^6 \; \mu g/g}\right] \qquad \text{(A-2)}$$

8. Isokinetic Variation. Determine the isokinetic variation in the sampling rate using Equation (5-7) of Method 5, 40 CFR 60, Appendix A and the raw data from this testing.

8.1 Acceptable Isokinetic Results. The following range sets the limit on acceptable isokinetic sampling results:

If $90\% \leq I \leq 100\%$, the results are acceptable. If the results are low in comparison with the emission standard and I is beyond the acceptable range, or if I is less than 90%, the Administrator may opt to accept the results. Otherwise, reject the results and repeat the test.

9. Alternate Test Methods for Inorganic Lead

9.1 Simultaneous Determination of Particulate and Lead Emissions. Method 5 as described in 40 CFR 60, Appendix A, is an acceptable alternate test method provided that: (1) 0.1N HNO_3 is used in the impingers; (2) a glass fiber filter with a low lead background is used; and (3) the entire train contents, including the impingers, are treated and analyzed for lead as described in Section 5 of this Test Method.

9.2 Filter located Between Third and Fourth Impinger. Location of the filter between the third and fourth impinger is an acceptable alternative method provided that the filter is included in the analysis for lead.

9.3 In-Stack Filter. Use of an in-stack filter is an acceptable alternate method provided that: (1) the in-stack filter is followed by a glass-lined probe and at least two impingers that each contain 100 ml of 0.1N HNO_3; and (2) the probe and impinger contents are recovered and analyzed for lead.

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APPENDIX B

PROCEDURE FOR DETERMINING THE ALKYL LEAD EMISSIONS FROM ALKYL LEAD MANUFACTURING PLANTS

PROCEDURE FOR DETERMINING THE ALKYL LEAD EMISSIONS FROM ALKYL LEAD MANUFACTURING PLANTS

U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL MONITORING AND SUPPORT LABORATORY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

MARCH 1978

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PROCEDURE FOR DETERMINING THE ALKYL LEAD EMISSIONS FROM ALKYL LEAD MANUFACTURING PLANTS

1. Principle and Applicability

1.1 Principle. Alkyl lead emissions are extracted from the source, collected in ICl solution, and analyzed by atomic absorption spectrometry using an air-acetylene flame.

1.2 Applicability. This method is applicable for determining the lead emissions from alkyl lead manufacturing plants.

2. Range, Sensitivity, Precision, and Interferences

The values given below are typical of the method's capabilities. Absolute values will vary for individual situations depending on the type of instrument used, the lead line, and operating conditions.

2.1 Range. The upper range of the method is unknown, but, in theory, the test method as described here can quantitatively collect approximately 10 g of tetraethyl lead. The upper range could be increased by increasing the volume of ICl used and by adding additional impingers. The lower limit of the method as described here is approximately 10 μg of lead alkyl as lead, if the Alternate Analytical Procedure (Section 8.1) is used and the final dilution is 25 ml.

2.2 Analytical sensitivity. Typical sensitivities for a 1% change in absorption (0.0044 absorbance units) are 0.2 and 0.5 μg Pb ml^{-1} for the 217.0 and 283.3 nm lines, respectively.

2.3 Precision. The within-laboratory precision, measured as the coefficient of variation, was determined at an alkyl lead manufacturing plant vent stack using four trains sampling simultaneously. The average run concentration for the five sampling runs was 265 to 369 μg Pb m^{-3}. The percent coefficient of variation for each run, which is determined by expressing the standard deviation of the run as a percentage of the run mean concentration, ranged from 1.8 to 8.2%. The average precision for all five runs was 3.8% of the mean concentration.

2.4 Interferences. Sample matrix effects may interfere with the analysis for lead by flame atomic absorption. If the analyst suspects that the sample matrix is causing erroneous results, the presence of these matrix effects can be verified and frequently corrected for by carrying out the analysis using the Method of Standard Additions on samples previously treated using the Alternate Analytical Procedure (Section 8.1)

3. Apparatus

3.1 Sampling Train. The sampling train is shown in Figure B-1, and component parts are discussed below.

3.1.1 Probe. Glass, Nylon or Teflon are acceptable.

3.1.2 Impingers. Smith-Greenburg. The two Smith Greenburg impingers must be connected in series using a leak-free glass connector. Silicone grease may be used if necessary to prevent leakage.

3.1.3 Acid Trap. Mine Safety Appliances Air Line Filter, Catalogue Number 81857 with acid absorbing cartridge and suitable connections, or equivalent.

3.1.4 Temperature Gauge. Dial thermometer, thermocouple, or

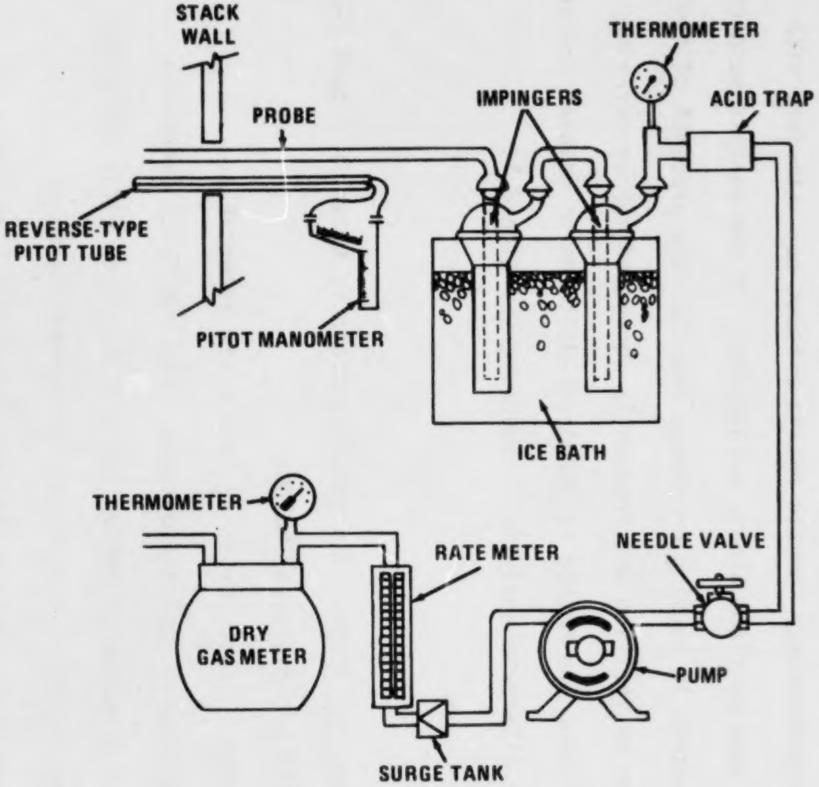

Figure B-1. Alkyl lead sampling train.

equivalent to measure the temperature of the gas in the stack, in the impinger bath and in the dry gas meter to 3°C(5.4°F).

3.1.5 Valve. Needle valve to regulate sample gas flow.

3.1.6 Pump. Leak-free diaphram pump, or equivalent, to pull gas through the train. It is suggested that a small tank be installed between the pump and the rate meter to eliminate the pulsation effect of the diaphram pump on the rate meter.

3.1.7 Volume Meter. Dry gas meter, sufficiently accurate to measure the sample volume within 2%, calibrated at the selected flow rate and conditions actually encountered during sampling, and equipped with a temperature gauge (dial thermometer, or equivalent) capable of measuring temperature to within 3°C (5.4°F).

3.1.8 Barometer. Mercury, aneroid, or other barometers capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby National Weather Service station, in which case the station value (which is the absolute barometric pressure) shall be requested, and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

3.1.9 Pitot Tube. Type S, as described in Section 2.1 of Method 2, 40 CFR 60, Appendix A, or other device approved by the Administrator. The Pitot tube shall be attached to the probe to allow constant monitoring of the stack gas velocity during testing for lead. The Type S pitot tube assembly shall have a known coefficient, determined as outlined in Section 4 of Method 2 (40 CFR 60, Appendix A).

3.1.10 Differential Pressure Gauge. Inclined manometer or equivalent device as described in Section 2.2 of Method 2, 40 CFR 60, Appendix A, to be used for velocity head (Δp) readings.

3.2 Sample Recovery

3.2.1 Wash bottle. Polyethylene or glass, 500 ml.

3.2.2 Storage bottles. Polyethylene or glass, 500 ml, narrow mouth with screw cap closures.

3.3 Analysis

3.3.1 Volumetric Flask. Class A with penny head standard taper stoppers. 100, 250, 500, and 1000 ml.

3.3.2 Volumetric Pipets. Class A. 1, 2, 3, 4, and 5 ml.

3.3.3 Graduated Cylinder. 100 ml.

3.3.4 Atomic Absorption Spectrophotometer. Equipped with lead hollow cathode or electrodeless discharge lamp.

3.3.5 Acetylene. The grade recommended by the instrument manufacturer should be used. Change cylinder when pressure drops below 50-100 psig.

3.3.6 Air. Filtered to remove particulate, oil, and water.

3.3.7 Cleaning. All glassware should be scrupulously cleaned. The following procedure is suggested. Wash with laboratory detergent, rinse, soak for 4 hr in 20% (v/v) HNO_3, rinse 3 times with distilled-deionized water, and dry in a dust free manner.

4. Reagents

4.1 Sampling

4.1.1 Distilled Water. Meeting ASTM specifications for Type 1

Reagent Water-ASTM Test Method D-1193-72. This water must be used in all dilutions and solution preparations.

4.1.2 Hydrochloric Acid. Concentrated ACS reagent grade or equivalent.

4.1.3 Potassium Iodide. Reagent grade.

4.1.4 Potassium Iodide Solution, 25% by weight. Dissolve 250 g of potassium iodide in distilled water and dilute to 1 liter with distilled water.

4.1.5 Potassium Iodate. Reagent grade.

4.1.6 Iodine Monochloride Stock Solution, 1.0M. To 800 ml of 25% potassium iodide solution (Reagent 4.1.4) add 800 ml of concentrated hydrochloric acid (Reagent 4.1.2). Cool to room temperature. With vigorous stirring, slowly add 135.5 g of potassium iodate and continue stirring until all free iodine (dark blue color) has dissolved to give a clear, orange-red solution. Cool to room temperature and dilute to 1800 ml with distilled water. The solution should be kept in the dark to avoid degradation.

4.1.7 Iodine Monochloride Absorbing Solution for Lead Alkyl Compounds, 0.2 M. Dilute 200 ml of the ICl stock solution (Reagent 4.1.6) to 1000 ml using distilled water. Store in glass bottles in the dark. Discard any unused solution after 60 days.

4.2 Sample Recovery.

4.2.1 All sample exposed surfaces should be washed with 0.2 M ICl (Reagent 4.1.7).

4.3 Analysis.

4.3.1 Nitric Acid. Concentrated ACS reagent grade or equivalent.

4.3.2 Sample Dilution Reagent, 0.2 M ICl (Reagent 4.1.7).

4.3.3 Lead Nitrate. Reagent grade.

4.3.4 Stock Lead Solution, 1000 µg Pb ml^{-1}. Dissolve 0.1598 g of lead nitrate (Reagent 4.3.3) in 60 ml of distilled water, add 2 ml of concentrated HNO_3 (Reagent 4.3.1) and dilute to 100 ml using distilled water. Store in polyethylene bottle. Commercially available certified lead standard solutions may be used.

4.3.5 Working Standard Lead Solutions for Spectrophotometer Calibration, 0, 4, 8, 12, 16, and 20 µg Pb ml^{-1}. Pipet 0.0, 1.0, 2.0, 3.0, 4.0, and 5.0 ml aliquots of the stock lead standard solution (Reagent 4.3.4) into 250 ml volumetric flasks. Add 5 ml concentrated HNO_3 to each flask and dilute to volume with distilled, deionized water. These working standards contain 0.0, 4.0, 8.0, 12.0, 16.0, and 20.0 µg Pb ml^{-1}, respectively. Additional standards at other concentrations should be prepared in a similar manner as needed.

5. Procedure

5.1 Sampling.

5.1.1 Preparation of Collection Train. Add 125 ml of 0.2 M ICL to each Smith-Greenburg impinger. Assemble the train as shown in Figure B-1. Place crushed ice and water around the impingers.

5.1.2 Leak-check Procedure. A leak check prior to the sampling run is optional; however, a leak check after sampling is completed is mandatory. The leak-check procedure is as follows:

Temporarily attach a suitable (e.g. 0-40 cm^3 min^{-1} rotameter to the outlet of the dry gas meter and place a vacuum gauge at or near the probe inlet. Plug the probe inlet, pull a vacuum of at least 250 mm Hg (10 in. Hg), and note the flow rate as indicated by the rotameter. A leakage rate not in excess of 2% of the average sampling rate is acceptable. Note: carefully release the probe inlet plug before turning off the pump.

It is suggested (not mandatory) that the pump be leak checked separately. If done prior to the sampling run, the pump leak check shall precede the leak check of the sampling train described immediately above, if done after the sampling run, the pump leak check shall follow the train leak check. To leak check the pump, proceed as follows: Disconnect the drying tube from the probe-impinger assembly. Place a vacuum gauge at the inlet to either the drying tube or the pump, pull a vacuum of 250 mm Hg (10 in. Hg), plug or pinch off the outlet of the flow meter, then turn off the pump. The vacuum should remain stable for at least 30 sec.

5.1.3 Preliminary Determinations. Select the sampling site and the number of points for a velocity traverse of the stack according to Method 1, 40 CFR 60, Appendix A or as specified by the Administrator. Determine the stack pressure, temperature, and range of velocity head using Method 2, 40 CFR 60, Appendix A; it is recommended that a leak check of the Pitot lines (See Method 2, Section 3.1) be done. Use these measurements to select a point in the stack at which to position the inlet to the probe and to determine the sampling rate that will be used in the testing.

If the volumetric flow in the stack is not expected to change by more than ± 10% during a test run, then single point, constant rate sampling will be acceptable. If the volumetric flow is expected to change by more than ± 10% during the run, then single point, proportional sampling shall be required unless directed otherwise by the Administrator.

5.1.4 Sample Collection. Record the initial dry gas meter volume reading and temperature, the stack velocity and temperature, and the barometric pressure. Use the criteria in Section 5.1.3 (Preliminary Determinations) to decide if proportional sampling or constant-rate sampling will be employed.

To begin sampling, position the tip of the sampling probe at the sampling point, connect the probe to the bubbler, and start the pump. Adjust the sample flow rate (to the desired proportional rate or the constant rate as necessary) to obtain a flow of 1.5 to 3.0 l min^{-1} through the train as indicated by the rotameter. (If proportional sampling is used, maintain the flow through the train within ± 10% of the desired proportional flow rate. If constant rate sampling is used, maintain a constant flow rate within ± 10% during the sample.)

At 15-min intervals or shorter if necessary because of stack conditions, record the following information: (1) dry gas meter and stack temperature (2) volume reading of the dry gas meter and (3) indicated rotameter flow rate. As necessary add more ice to the impinger box to maintain a temperature in the impinger box between 0° and 10°C. At the conclusion of each run, turn off the pump, remove probe from the stack, and record the final readings. Conduct a leak check as in Section 5.1.2. (This leak check is mandatory). If a leak is found, void the test run and repeat the run.

Samples should be taken over such a period or periods as necessary to accurately determine the maximum emissions that occur in a 24-hr period. In the case of the cyclic operations, sufficient tests shall be made to allow accurate determination of the emissions that occur over the duration of the cycle.

5.2 Sample Recovery. Disconnect the probe from the impingers and transfer the impinger contents to a 500-ml polyethylene (or glass) bottle. Wash each impinger twice with 25 ml of 0.2 M ICl solution and add the washes to the polyethylene or glass bottle. Wash the probe with a minimum of 50 ml of 0.2 M ICl and add this wash to the sample recovery bottle that contains the impinger wash. Seal and identify the container and mark the fluid level on the bottle or record the total weight.

For a blank place 50 ml of the 0.2 M ICl solution in a separate sample recovery bottle.

5.3 Sample Analysis. Note the level of liquid in the container or the weight of the container and confirm if any sample was lost during shipment. Note this on the data sheet. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results.

Transfer the contents of the storage container to a 500-ml volumetric flask and dilute to volume with 0.2 M ICl. If the expected concentration of lead in the sample exceeds 15 μg Pb ml^{-1}, dilute an aliquot of the sample with 0.2 M ICl to bring the lead concentration into the linear absorbance range of the spectrophotometer as indicated by the manufacturer.

Calibrate the spectrophotometer as described in Section 6.5 and analyze the source samples by aspirating them into the flame. Record the equilibrium absorbance. Analyze each sample three times in this manner and average the absorbances.

Similarly, aspirate a sample of the ICl blank and record the absorbance.

6. Calibration

Maintain a laboratory log of all calibrations.

6.1 Metering System

6.1.1 Initial Calibration. Before its initial use in the field, first leak check the metering system (drying tube, needle valve, pump, rotameter, and dry gas meter) as follows: place a vacuum gauge at the inlet to the drying tube and pull a vacuum of 250 mm (10 in.) Hg; plug or pinch off the outlet of the flow meter, then turn off the pump. The vacuum shall remain stable for at least 30 sec. Carefully release the vacuum gauge before releasing the flow meter plug.

Next, calibrate the metering system (at the sampling flow rate specified by the method) as follows: connect an appropriately sized wet test meter (e.g., 1 liter per revolution) to the inlet of the drying tube. Make three independent calibration runs, using at least five revolutions of the dry gas meter per run. Calculate the calibration factor, γ (wet test meter calibration volume divided by the dry gas meter volume, both volumes adjusted to the same reference temperature and pressure), for each run and average the results. If any γ value deviates by more than 2% from the average, the metering system is unacceptable for use. Otherwise, use the average as the calibration factor for subsequent test runs.

6.1.2 Post Test Calibration Check. After each field test series, conduct a calibration check as in Section 6.1.1 above, except for the following variations: (1) the leak check is not to be conducted, (2) three, or more revolutions of the dry gas meter may be used, and (3) only two independent runs need be made. If the calibration factor does not deviate by more than 5% from the initial calibration factor (determined in Section 6.1.1), then the dry gas meter volumes obtained during the test series are acceptable. If the calibration factor deviates by more than 5% recalibrate the metering system as in Section 6.1.1 and for the calculations use the calibration factor (initial or recalibration) that yields the lower gas volume for each test run.

6.2 Thermometers. Calibrate against mercury-in-glass thermometers.

6.3 Rotameter. The rotameter need not be calibrated but should be cleaned and maintained according to the manufacturer's instruction.

6.4 Barometer. Calibrate against a mercury barometer.

6.5 Spectrophotometer. Measure the absorbance of the standard solutions using the instrument settings recommended by the spectrophotometer manufacturer. Repeat until good agreement is obtained between replicates. Plot the absorbance (y-axis) versus concentration in μg Pb ml^{-1} (x-axis). Draw or compute a straight line through the linear portion of the curve. Do not force the calibration curve through zero, but if the curve does not pass through the origin or at least lie closer to the origin than $\pm$ 0.003 absorbance units, then check for incorrectly prepared standards and for curvature in the calibration curve.

To determine the stability of the calibration curve, run a blank and a standard after every five samples and recalibrate as necessary.

7. Calculations

7.1 Nomenclature.

A_s = Stack area, m^2

$(Pb)_o$ = Total μg lead in the source samples after correcting for all dilutions.

P_{bar} = Barometric pressure at the sampling site, mm Hg.

P_s = Absolute stack gas pressure, mm Hg.

R = Rate of lead emission, g/day.

T_m = Absolute average dry gas meter temperature, K.

T_s = Absolute stack temperature, K.

v_s = Average stack gas velocity, m/sec.

V_m = Total volume of gas sample as measured by the dry gas meter.

Y = Dry gas meter calibration factor.

7.2 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to stack conditions:

$$V_{Total} = V_m \left(\frac{Tm}{Ts}\right) \left(\frac{P_{bar}}{Ps}\right) \gamma \qquad \text{(B-1)}$$

7.3 Stack Gas Velocity. Calculate the stack gas velocity at stack conditions using Equation (2-9) of Method 2, 40 CFR 60 Appendix A; use velocity head, temperature, and pressure data from the alkyl lead testing.

7.4 Total Lead in Source Sample. For each source sample correct the average absorbance for the contribution of the ICl blank. Use the calibration curve and this corrected absorbance to determine the lead concentration in the sample as aspirated into the spectrophotometer.

Calibrate the total lead content (μg) in the original source sample $(Pb)_0$; correcting for all dilutions made to bring the lead concentration into the linear range of the spectrophotometer.

7.5 Total Lead Emission. Calculate the total amount of lead emitted from each stack per day using Equation (B-2). This equation is applicable for continuous operations. For cyclic operations, use only the time per day each stack is in operation. The total lead emissions from a source will be the summation of results from all stacks.

$$R = \left[\frac{(Pb)_o \; v_s \; A_s}{V_{Total}}\right] \left[\frac{86400 \text{ sec/day}}{10^6 \; \mu g/g}\right] \qquad \text{(B-2)}$$

8. Alternate Analytical Method

8.1 Alternate Analytical Method. The source samples may be analyzed for lead after converting all lead to an inorganic form. This can be done by gently evaporating an aliquot of the original source sample to dryness on a hot plate at low heat, heating on low heat until all color has disappeared, dissolving the residue in 5% (v/v) HNO_3 and diluting to known volume with 5% (v/v) HNO_3. The samples can then be analyzed for lead using the analysis procedure described in the test method.

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APPENDIX C

PROJECTING AUTOMOTIVE LEAD EMISSIONS FOR ROADWAY CONFIGURATIONS

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APPENDIX C

Projecting Automotive Lead Emissions for Roadway Configurations

The characterization of automotive lead emissions has been described in journal articles and in minimal EPA testing. In this work, it is generally agreed that (1) only a percentage of the lead burned in the fuel is exhausted and (2) that the percentage of lead exhausted varies with vehicle operating conditions. Experimental evidence shows that 70-80 percent of the lead burned in gasoline is emitted into the atmosphere, while 20-30 percent is retained in the engine, oil, and exhaust system (Hirschler, *et al.*, 1964, Ter Haar, *et al.*, 1972).

The Hirschler and Gilbert study obtained data from three passenger cars during a city-type driving cycle. These data showed that, on the average, the exhaust gas contained from 28.2% to 44.8% of the lead burned by the cars. At the completion of exhausted lead tests in all three cars, the amount of lead left in various zones of the engine and exhaust system was determined. From 21.1% to 27.8% of the lead burned by the cars was recovered from deposits in the exhaust system and engine, and in the lubricating oil and oil filters. Therefore, something less than 75% of the lead burned could have been present in the exhaust gas.

During operation under a test cycle of moderate speeds similar to city-type driving, three cars exhausted from 28% to 45% of the lead burned. When exhaust systems were fairly free of deposits, the emissions of lead were in the 20-25% range, but after the cars had been operated for several thousands of miles at moderate speeds, emissions increased into the 35-55% range. Individual tests showed wide variations which indicate that a random factor, probably deposit flaking in the exhaust system, is involved in the process of exhausting lead.

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The Ter Haar study calculated a lead balance based on the assumption that 25% of the lead remains in the automobile. In the emission tests, an average of 21.4% of the lead burned was emitted from 26 cars on the Federal hot cycles, while the cold cycles emitted 43.9% of the lead burned. With the Federal cycle weighted 65% for the hot cycles and 35% for the cold cycles, the calculated percentage of burned lead emitted during the fall Federal Cycle is 29.2%.

The 29% for the full Federal cycle and the 25% which remains in the car accounted for 54% of the lead burned. Ter Haar et al. assume that the remaining 46% is emitted during heavy accelerations and decelerations.

This analysis was tested in a total lead balance study of a car driven on a mileage accumulation route for 12,000 miles. The exhaust from the car was measured with a total filter. Ter Haar et al. accounted for 84.3% of the lead burned. They believe that the 15% unaccounted for was lost during handling of the exhaust system and the total filter. Although the total lead exhausted overall was about 55% of the lead burned, it should be noted that it was only 36% for the first 6000 miles and increased to 73% for the last 6000 miles. Therefore, if the exhaust system is not changed, it is likely that this car will continue to exhaust 75% or more of the lead burned.

Emissions During City-Type Driving

Several studies have been performed measuring lead emissions under different driving conditions. The first comprehensive study of automotive lead emissions was performed by Hirschler and Gilbert. The Hirschler and Gilbert study measured automotive lead emissions for constant speed dynamometer tests and a city-type driving cycle. The city-type driving cycle was a repeated cycle of idling, accelerating, decelerating and cruising over 110 miles at an average speed of 22 miles per hour. The cruise speeds were 25 and 40 miles per hour. The city driving cycle data showed that, on the average, the exhaust gas contained from 28.2 to 44.8 percent of the lead burned by the cars. These numbers were averaged to derive an emission factor of 0.365 (36.5% of burned lead is exhausted) to estimate the emissions for a city-suburban roadway configuration.

In comparison, Bradow (1976) measured lead emissions from three 1970-1974 model year cars on the Federal Test Procedure cycle. For these tests, the percentage of burned lead exhausted ranged from 10.8 percent to 21.4 percent.

While the Hirschler and Gilbert data for city-suburban driving are from 1953, 1954, and 1957 model year automobiles, it seems reasonable to assume that lead emissions from these cars are representative of more recent model year vehicles. Figure 1 shows that the Hirschler and Gilbert data for cruise-speed driving are within the bounds of the data presented in other studies on the percentage of burned lead exhausted. The fact that the Hirschler and Gilbert numbers in Figure 1 are reasonable is important since these are the most complete data that represent city-suburban driving.

Emissions During Cruise-Speed Driving

Habibi (1973) tested a 1966 model year vehicle using the Federal mileage accumulation schedule (Federal Register, 1968) under steady-state constant-speed conditions. Exhaust measurements were made at four nominal test mileages during the mileage accumulation schedule. The steady-state operation emissions were measured at 20,45, and 70 miles/hour. The tests ranged from 200 to 400 miles in duration and were run on a fuel containing 3 grams of lead per gallon. The lead emissions from these tests are shown in Figure 1. The ranges and average emission rates for each of the three cruise speeds are shown on the graph.

Ter Haar et al. studied automotive exhaust particulates by testing 26 cars. Ten were owned by the Ethyl Corporation in commuter service and 16 were employee-owned. The Ethyl Corporation cars were 1963-1968 models that had been driven from 20,000 to 62,000 miles. The employee cars were all 1966 models with 17,000 to 92,000 miles of service. The test conditions included cruise at 25, 45, and 60 miles/hour. The 26-car average results for the three speeds are shown in Figure 1.

Sampson and Springer (1973) and Ganley and Springer (1974) measured automotive lead using a 1970 350-in^3 Chevrolet V-8 production engine mounted on a dynamometer. A simulated exhaust system was connected to the engine. The majority of the tests were performed at a load equivalent to a full-size 1970 Chevrolet cruising at 55 miles/hour. For each of the two studies, an average lead emission rate is shown in Figure 1.

Dr. Ron Bradow of EPA, ESRL tested four in-use vehicles for lead emissions in 1976. These four vehicles ranged from 1963-1974 model years and had 37,000-54,000 accumulated miles. Twenty-nine test runs were performed using the Sulfate Emissions Test, the Fuel Economy Test, and the Federal Test Procedure (Federal Register No. 221, 1972). The lead emissions data from the Sulfate Emissions Test and the Fuel Economy Test are included in Figure 1 because these tests are representative of cruise-speed driving.

The automotive cruise speed emissions data from journal articles and EPA testing were used to develop a curve for determining lead emission factors. This curve is a conservative estimate of future year lead emissions and is shown on Figure 1.

Emissions During Acceleration Periods

Data collected by Hirschler and Gilbert and Ter Haar et al. on lead emissions from automobiles show that the highest emission rates occur when cars accelerate from a stop or a low cruise speed (20 mph) to a much higher speed (60 mph). Therefore, an area where vehicles are accelerating on expressway access ramps onto heavily traveled expressways has the potential for high concentrations of ambient lead. The accurate modeling of such a situation is limited due to the scarcity of data on acceleration emissions. However, data from the journal articles by Hirschler and Gilbert and Ter Haar can be used to estimate an emission factor for accelerations to 60 miles per hour.

Hirschler and Gilbert conducted full-throttle acceleration tests on a single exhaust 1954 car and a dual exhaust 1953 car. A series of tests were made on the 1954 model year car after 25,000 miles of deposit accumulation in the exhaust system. In the first test, a series of three full-throttle accelerations from 20 to 60 mph were made, and the lead exhaust was collected and classified. This was followed by a test in which exhausted lead was collected from a series of nine similar full-throttle accelerations. The same type of tests were run on the 1953 model year car. However, the data from the 1953 car are less complete because the sample from the second test of nine accelerations was lost. The results of the Hirschler and Gilbert tests are shown below:

	% burned lead emitted	
	Single Exhaust 1954 car (12 tests)	Dual Exhaust 1953 car (3 tests)
Full-throttle acceleration 20 to 60 mph	870 to 1230	1990

Ter Haar et al. tested 26 1963-1968 model year cars for acceleration emissions. Ten of these cars were owned by the Ethyl Corporation in commuter service. These cars ranged from model year 1963-1968 and in accumulated mileage from 20,000-62,000 miles. The other 16 cars were employee-owned 1966 model year cars with 17,000-92,000 accumulated miles. The results of the Ter Haar study indicate that an average of 1119% of the lead burned is exhausted during full throttle acceleration (0-70 and 30-70 mph).

Deriving a specific emission factor for acceleration conditions from the aforementioned studies is a difficult task. Ter Haar's data seem to be more useful because 26 different cars were tested and more recent model year cars were used. While Hirschler and Gilbert made multiple runs, only two cars were tested and these were 1953-1954 model year vehicles. Therefore, the best emission factor estimate for a full-throttle acceleration from 0-60 mph is that approximately 10 times the lead burned is exhausted by the car.

Automotive Lead Projections

Based on data on automotive lead emissions under city, cruise speed, and acceleration conditions, calculations of lead emission rates were made for seven roadway configurations. These seven roadway configurations were chosen to approximate worst-case traffic volumes for the roadway types considered. However, it is possible that particular roadways may have higher traffic volumes, and hence higher emission rates than those modeled here.

Lead emissions from automobiles are projected for future years for seven roadway configurations based on emissions at different vehicle speeds, the lead content of gasoline, and an average fleet fuel economy. Emission rates are calculated based on equation (1):

$$\frac{[\text{Emission Factor}]\ [\text{Lead Content of Gas (g/gal)}] \times \text{ADT}}{[\text{Fuel Economy (miles/gal)}]} = \begin{array}{c}\text{Emission Rate}\\ \text{(g/road mile-day)}\end{array} \quad (1)$$

Using equation (1), emission rate estimates were made for the seven roadway configurations. These results are presented in Table 6. [Note: To calculate the emission rate in units of grams/meter/second, equation (1) should be corrected by dividing by 139,017,600.]

Fuel Economy

Fuel economy projections are based on the average fuel economy standards (15 USC 2002). In this law, fuel economy standards are established for 1978, 1979, 1980 and 1985. Past year average fuel economies are known through 1973 (EPA 1974). Fuel economy values for other years are determined using a straight-line interpolation. Average fuel economies, based on the fuel economy standards, are shown in Table 4 for the projection years.

The fuel economy calculation at each roadway configuration is performed to account for the effect of vehicle speed on fuel economy. The fuel economy of a car is maximized when it is cruising at 30-40 miles/hour. In addition, the fuel economy during highway driving is better than under stop-and-go city driving. Therefore, an accurate estimate of fuel economy on a roadway configuration must take traffic flow characteristics into account.

Table 1 shows fuel economies for different model year vehicles. These fuel economies are based on a combined city/highway driving cycle. Combined fuel economy is a weighted average of the city and highway estimates based on Federal Highway Administration studies of average U. S. driving patterns. This value (which assumes 55% city and 45% highway driving) is what the average driver can expect in overall summer driving on level roads after the car has been broken in. City fuel economy reflects trips for local errands, driving to work, and general stop-and-go driving in urban and suburban areas. Highway fuel economy reflects long-distance driving on non-urban roads and on interstate highways at a speed averaging approximately 50 miles/hour with no stops.

While the values in Table 1 are accurate estimates of nationwide fuel economy, they are not representative of the fuel economy on specific roadways. The coefficients in Table 2 can be used to determine a correction factor to account for vehicle speed at the study location. The coefficients in this table are normalized to 32.7 miles/hour, the average speed of the combined fuel economy cycle. These numbers were derived from the fuel economy correction factors presented in an EPA interim report (EPA 1977). These correction factors are based on the Federal Test Procedure with an average speed of 19.6 miles/hour. The normalized correction factors were calculated by determining the FTP correction factor at 32.7 miles/hour for each model year, then dividing the A coefficients for each model year evaluated at 19.6 miles/hour by the correction factor for each model year for 32.7 miles/hour. This normalization makes the Table 2 coefficients compatible with combined cycle fuel economies.

Fuel economy calculations for the projection years were performed following these steps:

1. Knowing the average vehicle speed for the roadway configuration, the coefficients from Table 2 and the vehicle speed are used in equation (2) below to calculate a speed dependent fuel economy correction factor for each model year.

$$\text{Fuel Economy Correction Factor} = A_0+A_1S+A_2S^2+A_3S^3+A_4S^4 \qquad (2)$$

where Ai = correction factors from Table 2

S = vehicle speed (miles/hour)

2. Multiply the fuel economy speed correction factors for each model year calculated in (1) by the City/Highway Combined Fuel Economy (Table 1) and the fraction of annual travel by model year (Table 3). The products for each model year are summed to determine the base year (1974) composite fuel economy. This calendar year composite fuel economy represents the combined cycle fuel economy at average speed S.

3. The base year composite fuel economy calculated in step (2) is divided by the base year (1974) average fleet fuel economy from Table 4 to determine the ratio of the fuel economy at the study location to the nationwide average fleet fuel economy. This ratio is then used to estimate the fuel economy at the study location for future years by multiplying it by the average fleet fuel economy in Table 4 for each projection year.

4. The fuel economies calculated in (3) above are representative of combined city/highway driving. These numbers should be corrected for a study location with traffic that is primarily free-flow or city-type driving rather than combined city/highway. To correct for free-flow traffic, multiply each fuel economy by 1.2297. The correction factor for city-type driving is 0.866. (Austin et al., 1975).

Lead Content of Gas

The average lead content of gas for future years is calculated based on the promulgated lead phase-down schedule (Federal Register, 1976). The "pooled average lead content" of gas is based on the percentage of cars using unleaded gas and the lead content of leaded and unleaded gas. For the calculations in Table 5, the number of Pre-75 and Post-74 vehicles was determined using the fraction of annual light-duty vehicle travel by model year schedule in AP-42, Supplement 5. The "pooled average lead content" is as given in the lead phase-down regulations and the lead content of unleaded gas is assumed to be 0.05 grams/gallon. From these numbers, the maximum possible lead content of leaded gas can be calculated for each calendar year using equation (3):

$$\begin{aligned}&[\%\ \text{Pre-75 vehicles}]\ [\text{Lead content of leaded gas (g/gal)}]\\ +\ &[\%\ \text{Post-74 vehicles}]\ [\text{Lead content of unleaded gas (g/gal)}] =\\ &[100\%]\ [\text{Pooled average lead content (g/gal)}]\end{aligned} \qquad (3)$$

Assuming that the lead content of leaded gasoline will not exceed 2.0 grams/gallon, *the probable pooled average lead content of* gas was calculated. The lead content of gas calculations are summarized in Table 5.

Automotive Lead Particle Size Distributions

The primary work on particle size distributions has been performed by Hirschler and Gilbert, 1964 and Habibi, 1973. Hirschler and Gilbert show that the weight percentage of exhausted lead greater than five microns increases as vehicle speed increases. Their testing was performed on three cars equipped with V-8 engines and manual transmissions. The cars each had 12,500 accumulated miles.

The accuracy of Hirschler and Gilbert's data has been questioned in view of the collection technique---i.e., total collection and subsequent dispersion and fractionation of the particles. Such operations can lead to agglomeration of small particles leading to inaccurate size distribution data. Because of possible inaccuracies in Hirschler and Gilbert's particle size data for different vehicle speeds, it is inappropriate to use these values in modeling roadway configurations.

Habibi's data on particle size distributions seems to be the best available. Habibi measured lead emissions from a 1966 model vehicle equipped with a 327-CID engine operating on gasoline containing three grams of lead per gallon. The vehicle was driven on a programmed chassis dynamometer using the Federal mileage accumulation schedule (Federal Register, 1968). The lead particle size distribution data is presented as a function of accumulated mileage in Figure 2. This seems to be the most accurate available data on lead particle size distribution emitted from an automobile under city-type driving. While Figure 2 shows how particle size varies as a function of accumulated mileage, it should also be noted that the particle size distribution varies with the mode of vehicle operation. The percentage of large particles increases with the severity of operation.

Summary

Table 6 summarizes the emission rates for seven roadway configurations. As shown in the table, automotive lead emission rates at a specific location are dependent on vehicle speed, the lead content of gasoline, fuel economy, and traffic volume. The relationship of these variables is summarized in equation (1).

$$\frac{[\text{Emission Factor}]\,[\text{Lead Content of Gas (g/gal)}] \times \text{ADT}}{\text{Fuel Economy (miles/gal)}} = \underset{\text{(g/road mile-day)}}{\text{Emission Rate}} \qquad (1)$$

While total lead balances show that 70-80 percent of the lead burned in gasoline is emitted into the atmosphere, this number is not an accurate estimate of automotive emissions from a particular roadway. Estimates have been made for lead emission rates during city-type driving, cruise-speed driving, and acceleration periods so that specific roadways can be analyzed. Knowing the average speed, volume and flow characteristics of the traffic on a roadway, an estimate of the automotive lead emission rate can be made using the techniques described in this paper.

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Table 1

City/Highway Combined Fuel Economy

(miles/gallon)

Model Year	Fuel Economy
1974	15.15
1973	14.89
1972	15.20
1971	15.24
1970	15.42
1969	15.47
1968	15.60
1967	16.15

Table 2

Fuel Economy Correction Factors by Model Year

(Normalized to 32.7 miles/hour)

Model Year	A_0	A_1	A_2	A_3	A_4
Pre-controlled	2.4697E-2	7.55258E-2	-2.42452E-3	4.01469E-5	-2.68893E-7
1968	1.75941E-2	6.90954E-2	-2.01359E-3	3.19426E-5	-2.12343E-7
1969	3.43032E-3	7.24956E-2	-2.18976E-3	3.54015E-5	-2.36485E-7
1970	6.00124E-3	6.90443E-2	-1.98463E-3	3.13931E-5	-2.09286E-7
1971	9.76255E-3	6.84494E-2	-1.96781E-3	3.13719E-5	-2.11167E-7
1972	8.57745E-2	7.0882E-2	-2.15219E-3	3.57324E-5	-2.44316E-7
1973-74	6.29988E-2	5.96559E-2	-1.59874E-3	2.59441E-5	-1.84877E-7

Ref: Mobile Source Emission Factors--Interim Document (EPA 1977).

Fuel Economy Correction Factor = $A_0+A_1S+A_2S^2+A_3S^3+A_4S^4$

where S = vehicle speed

Table 3

Fraction of Annual Light-Duty Vehicle Travel by Model Year

Age Years	Fraction of Annual Travel
1	.112
2	.143
3	.130
4	.121
5	.108
6	.094
7	.079
≥8	.213

Ref: AP-42, Supplement 5

Table 4

Average Fleet Fuel Economy

(miles/gallon)

Calendar Year	Fuel Economy
1974	12.4
1977	13.3
1978	14.0
1979	14.8
1980	15.7
1981	16.8
1983	19.1
1985	21.7
1990	26.2
1995	27.4

Ref: U. S. Environmental Protection Agency,
A Report on Automotive Fuel Economy, Washington, D.C., February, 1974.

15 USC 2002

Table 5

Lead Content of Gasoline

Year	LEADED GASOLINE % Pre-75 Vehicles	Max. Possible Lead (grams/gal)	Probable Lead (grams/gal)	UNLEADED GASOLINE % Post-74 Vehicles	Lead (grams/gal)	Pooled Ave.*** Lead Content (grams/gal)	Probable Pooled Ave. Lead Content (grams/gal)
	A	B*	C	D	E	F	G**
1974	100.0	-	2.0	0.0	.05	-	2.0
1975	88.8	1.91	1.9	11.2	.05	1.7	1.7
1976	74.5	1.86	1.9	25.5	.05	1.4	1.4
1977	61.5	1.59	1.6	38.5	.05	1.0	1.0
1978	49.4	1.57	1.6	50.6	.05	0.8	0.8
1979	39.6	1.19	1.2	61.4	.05	0.5	0.5
1980	29.2	1.59	1.6	70.8	.05	0.5	0.5
1981	21.3	2.16	2.0	78.7	.05	0.5	0.5
1982	15.0	3.05	2.0	85.0	.05	0.5	0.34
1983	10.3	4.42	2.0	89.7	.05	0.5	0.25
1984	7.1		2.0	92.9	.05	0.5	0.19
1985	5.2		2.0	94.8	.05	0.5	0.15
1986	3.9		2.0	96.1	.05	0.5	0.13
1987	2.8		2.0	97.2	.05	0.5	0.11
1988	2.1		2.0	97.9	.05	0.5	0.09
1989	1.7		2.0	98.3	.05	0.5	0.08
1990	0		2.0	100.0	.05	0.5	0.05

*Column B = $\frac{F-(D \times E)}{A}$

**Column G = $(A \times C) + (D \times E)$

***Required by EPA Regulations

Table 6

Emission Rates for Roadway Configurations
[calculated using equation (1)]

Roadway	Year	Lead Content of Gasoline (g/gal)	Fuel Economy (miles/gal)	Average Daily Traffic (veh/day)	Emission Rate (g/m-sec)
	1974	2.0	20.0	50,000	1.94×10^{-5}
1. Rural	1977	1.0	21.4		9.08×10^{-6}
Limited Access	1978	0.8	22.6		6.94
4-lane	1979	0.5	23.9		4.07
Avg. Speed = 60 mph	1980	0.5	25.3		3.84
Emission Factor	1981	0.5	27.1		3.58
= .54	1983	0.25	30.8		1.58
	1985	0.15	35.0		8.27×10^{-7}
	1990	0.05	42.2		2.30
	1995	0.05	44.2		2.20
2. Residential	1974	2.0	15.2	5,000	1.04×10^{-6}
2-lane	1977	1.0	16.2		4.87×10^{-7}
Avg. Speed = 30 mph	1978	0.8	17.1		3.70
Emission Factor	1979	0.5	18.1		2.19
= .22	1980	0.5	19.2		2.06
	1981	0.5	20.5		1.93
	1983	0.25	23.3		8.48×10^{-8}
	1985	0.15	26.5		4.47
	1990	0.05	32.0		1.24
	1995	0.05	33.5		1.18

Table 6 (Cont)

Emission Rates for Roadway Configurations

Roadway	Year	Lead Content of Gasoline (g/gal)	Fuel Economy (miles/gal)	Average Daily Traffic (veh/day)	Emission Rate (g/m-sec)
3. Urban Expwy.	1974	2.0	20.9	118,000	3.29×10^{-5}
6-lane	1977	1.0	22.4		1.53
Avg. Speed = 48 mph	1978	0.8	23.5		1.16
Emission Factor	1979	0.5	24.9		6.88×10^{-6}
= .405	1980	0.5	26.4		6.51
	1981	0.5	28.3		6.08
	1983	0.25	32.1		2.68
	1985	0.15	36.5		1.42
	1990	0.05	44.1		3.90×10^{-7}
	1995	0.05	46.1		3.73
4. City Street	1974	2.0	10.0	28,000	4.23×10^{-6}
4-lane	1977	1.0	10.7		1.97
Avg. Speed = 16 mph	1978	0.8	11.3		1.49
Emission Factor	1979	0.5	11.9		8.84×10^{-7}
= .105	1980	0.5	12.7		8.35
	1981	0.5	13.6		7.80
	1983	0.25	15.4		3.43
	1985	0.15	17.5		1.81
	1990	0.05	21.2		5.00×10^{-8}
	1995	0.05	22.1		4.79

Table 6 (Cont)

Emission Rates for Roadway Configurations

Roadway	Year	Lead Content of Gasoline (g/gal)	Fuel Economy (miles/gal)	Average Daily Traffic (veh/day)	Emission Rate (g/m-sec)
5. Urban Expwy.	1974	2.0	20.0	108,000	2.33×10^{-5}
6-lane	1977	1.0	21.4		1.09
Avg. Speed = 38 mph	1978	0.8	22.6		8.29×10^{-6}
Emission Factor	1979	0.5	23.9		4.89
= .30	1980	0.5	25.3		4.60
	1981	0.5	27.1		4.30
	1983	0.25	30.8		1.89
	1985	0.15	35.0		1.00
	1990	0.05	42.2		2.76×10^{-7}
	1995	0.05	44.2		2.64
6. City Street	1974	2.0	10.0	28,000	1.47×10^{-5}
4-lane	1977	1.0	10.7		6.84×10^{-6}
Avg. Speed = FTP	1978	0.8	11.3		5.20
Emission Factor	1979	0.5	11.9		3.08
= .365	1980	0.5	12.7		2.89
	1981	0.5	13.6		2.71
	1983	0.25	15.4		1.19
	1985	0.15	17.5		6.29×10^{-7}
	1990	0.05	21.2		1.73
	1995	0.05	22.1		1.67

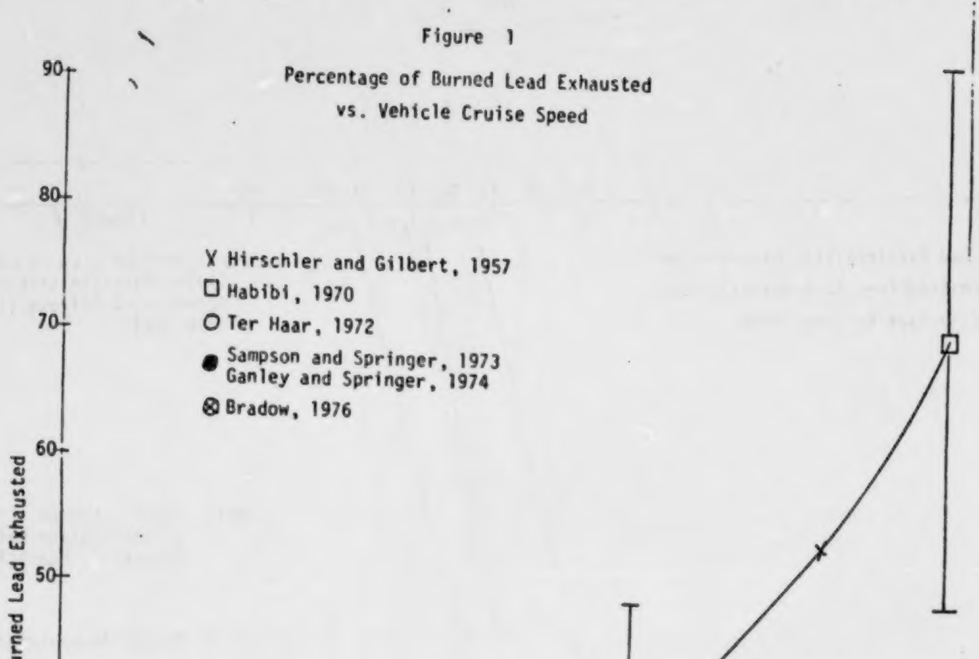
Table 6 (Cont)

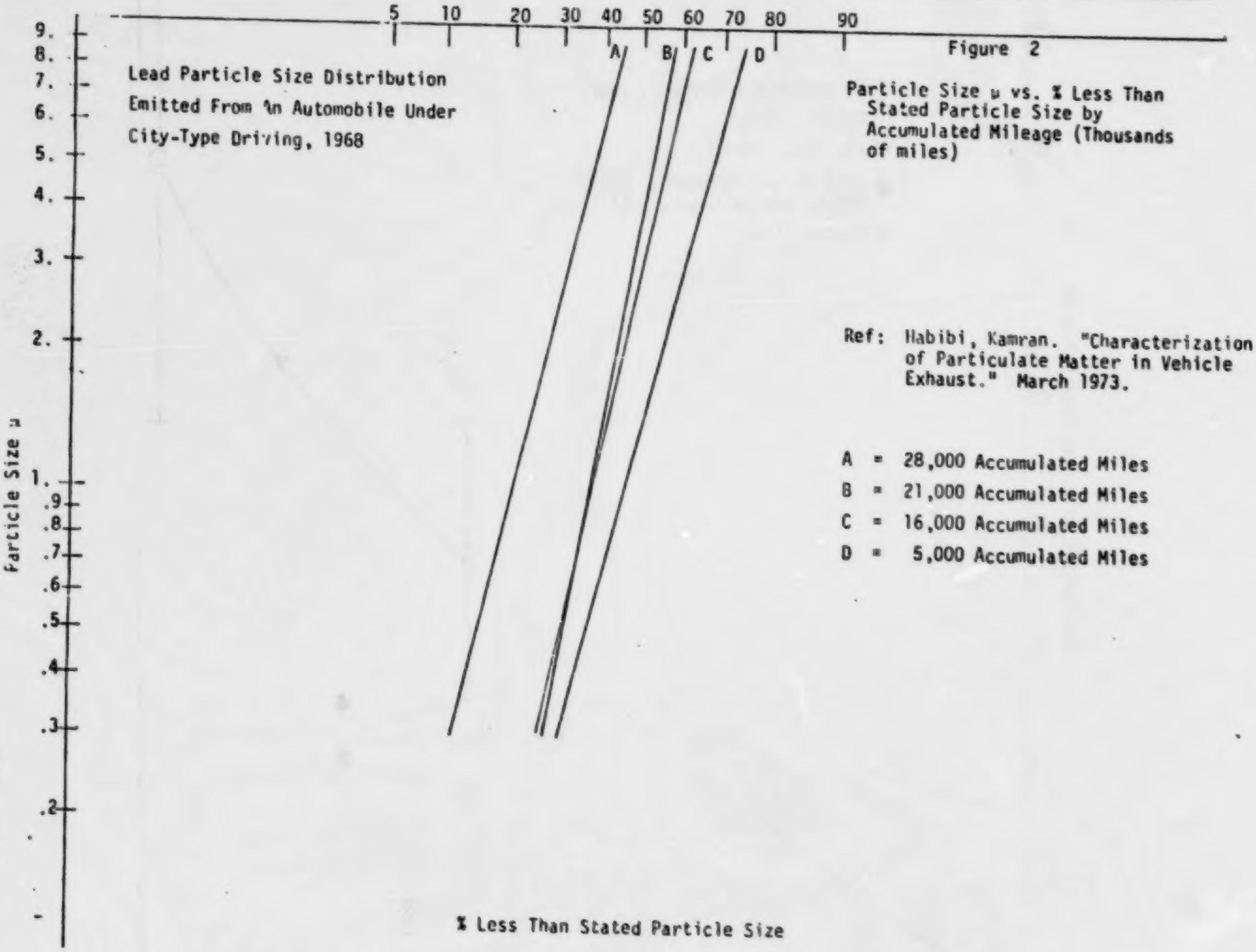
Emission Rates for Roadway Configurations

	Roadway	Year	Lead Content of Gasoline (g/gal)	Fuel Economy (miles/gal)		Average Daily Traffic (veh/day)	Emission Rate (g/m-sec)
7.	Acceleration Ramp	1974	2.0	10.0	20.0	Ramp = 24,300	3.80×10^{-4}
	1-lane	1977	1.0	10.7	21.4	Hwy. = 80,000	1.78
	Speed = 0-60 mph	1978	0.8	11.3	22.6		1.35
	Emission Factor	1979	0.5	11.9	23.9		7.96×10^{-5}
	= 10.0	1980	0.5	12.7	25.3		7.50
	Highway	1981	0.5	13.6	27.1		7.01
	8-lane	1983	0.25	15.4	30.8		3.01
	Avg. Speed = 60 mph	1985	0.15	17.5	35.0		1.63
	Emission Factor	1990	0.05	21.2	42.2		4.50×10^{-6}
	= .54	1995	0.05	22.1	44.2		4.30
				(Ramp)	(Hwy.)		

Figure 1

Percentage of Burned Lead Exhausted vs. Vehicle Cruise Speed





Lead Particle Size Distribution
Emitted From An Automobile Under
City-Type Driving, 1968

Figure 2

Particle Size μ vs. % Less Than Stated Particle Size by Accumulated Mileage (Thousands of miles)

Ref: Habibi, Kamran. "Characterization of Particulate Matter in Vehicle Exhaust." March 1973.

A = 28,000 Accumulated Miles
B = 21,000 Accumulated Miles
C = 16,000 Accumulated Miles
D = 5,000 Accumulated Miles

APPENDIX D

DEPOSITION OF PARTICLES AND GASES*

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*Excerpted from Slade, David H. (ed). Meteorology and Atomic Energy 1968. Prepared by Air Resources Laboratories, Research Laboratories, Environmental Science Services Administration, U.S. Department of Commerce, for the Division of Reactor Development and Technology, U.S. Atomic Energy Commission, Oak Ridge, Tennessee. July, 1968. Pp. 202-208.

5-3 DEPOSITION OF PARTICLES AND GASES (Isaac Van der Hoven)

List of Symbols

Symbols used frequently in Sec. 5-3 on the deposition of particles and gases are listed here. (The dimensions mass, length, time, and temperature are abbreviated as M, L, T, and D, respectively. The equation number indicates the first appearance of the symbol.)

C_D	Drag coefficient (dimensionless), Eq. 5.35
C_y, C_z	Sutton's virtual diffusion coefficients ($L^{n/2}$), Eq. 5.38
g	Gravitational acceleration (LT^{-2}), Eq. 5.35
h	Height of source above ground (L), Eq. 5.38
n	Sutton's parameter associated with stability (dimensionless), Eq. 5.38
Q', Q'_0	Initial source strength (MT^{-1}), Eq. 5.38
Q'_x	Depleted source strength at a distance, x, from the source (MT^{-1}), Eq. 5.42
r	Particle radius (L), Eq. 5.35
$\bar{u}$	Average value of the wind component in the direction of the mean horizontal vector wind (LT^{-1}), Eq. 5.38
v_d	Deposition velocity (LT^{-1}), Eq. 5.41
v_g	Fall velocity (LT^{-1}), Eq. 5.35
λ	Mean free path of air molecules (L), Eq. 5.37
μ	Atmospheric dynamic viscosity ($ML^{-1}T^{-1}$), Eq. 5.36
ρ	Particle density (ML^{-3}), Eq. 5.35
ρ_a	Atmospheric density (ML^{-3}), Eq. 5.35
σ_y, σ_z	Standard deviation of the distribution of material in a plume in the y and z directions (L), Eq. 5.44
$\bar{\chi}$	Average concentration (ML^{-3}), Eq. 5.38
ω	Amount of aerosol removed per unit time per unit area ($ML^{-2}T^{-1}$), Eq. 5.39

5-3.1 Gravitational Settling

The earth's gravitational field plays an important role in the deposition of particulate matter on the earth's surface. The rate of descent of the particle depends upon a balance between the aerodynamic drag force and the gravitational force exerted by the earth. For a smooth spherical particle, neglecting the effect of slip flow, this balance may be expressed as

$$\rho_a v_g^2 C_D = \frac{8}{3} r g \rho \qquad (5.35)$$

where the notation is as given in the list of symbols. Equation 5.35 cannot be solved directly for the fall velocity because the drag coefficient is an empirical function of the Reynolds number, Re, and therefore also of velocity. McDonald (1960) has conveniently plotted this empirical relation for $Re > 1.0$ from which values of fall velocity vs. particle size can be computed. For the Reynolds number range between 10^{-4} and 10, the relation $C_D = 24/Re$ may be used, and, since $Re = 2\rho_a v_g r/\mu$, Eq. 5.35 reduces to the familiar Stokes equation

$$v_g = \frac{2 r^2 g \rho}{9\mu} \qquad (5.36)$$

The effect of the slip flow upon the fall velocity is a function of the ratio of the mean free path of the air molecules to the particle size. It can be expressed by multiplying the fall velocity by a slip correction factor (Davis, 1945)

$$1 + \frac{\lambda}{r}\left[1.26 + 0.4 \exp\left(-\frac{1.1r}{\lambda}\right)\right] \qquad (5.37)$$

where λ is primarily a function of altitude.

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The effect of shape upon fall velocities is, on the average, to reduce the velocity by about [illegible] from that of a smooth sphere. Smooth ellipsoidal particles theoretically will vary in fall velocities by factors ranging from 0.5 to 1.04.

At fall velocities less than about 1 cm/sec, the effect of sedimentation is negligible, and vertical movement of the particle is largely controlled by the larger vertical turbulent and mean air motions. Figure 5.4 (after Hage, 1964) shows the fall velocity of smooth spheres with a density of 5 g/cm³ as a function of the altitude and particle diameter, with inertia terms and slip flow corrections taken into account where significant. It can be seen that the predominant factor affecting fall velocity is the particle size. Similar fall-velocity computations for a particle with a density of 2.5 g/cm³ are given by McDonald (1960a).

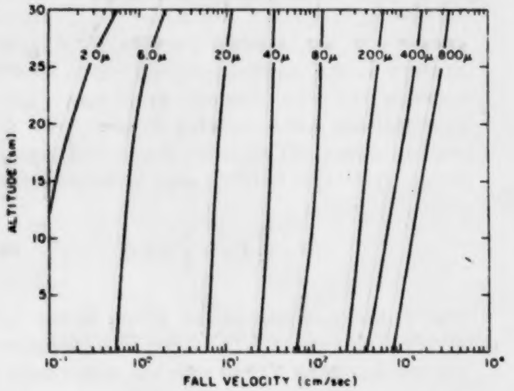

Fig. 5.4 — Fall velocity of smooth spheres with a density of 5 g/cm³ as a function of altitude and particle diameter (microns). (From Hage, 1964.)

In the range where the sedimentation rate is significant, the vertical transport of an initially airborne particle (fall velocity greater than about 1 cm/sec) depends upon horizontal as well as vertical transport and diffusion. For fall velocities ranging from about 1 to 100 cm/sec, the diffusion of a cloud of particles under homogeneous horizontal transport (no wind shear with height) can be described by assuming that the particles are diffused according to a statistical diffusion model, such as that of Sutton (1953), and at the same time that they will settle with appropriate fall velocities. For the case of an elevated plume, the effect is essentially that of the downward tilt of the plume center line, which can be expressed by replacing the constant height of the plume center line in the Sutton equation by a variable expression such that

$$\bar{\chi}\,(x,y,0) = \frac{2Q'}{\pi C_y C_z \bar{u} x^{2-n}} \exp\left\{-x^{n-2}\left[\frac{y^2}{C_y^2} + \frac{(h - x v_g/\bar{u})^2}{C_z^2}\right]\right\} \qquad (5.38)$$

With the assumption that the particles are removed (deposited) when they reach the ground–air interface, the deposition pattern can be described by the expression

$$\omega = v_g \bar{\chi}\,(x,y,0) \qquad (5.39)$$

where ω is the amount removed per unit time per unit area and $\bar{\chi}$ is the volumetric concentration pattern of the air at the surface.

Van der Hoven (1963) used this tilted plume model to describe the observed deposition pattern of radioactive effluents and included a cloud depletion factor (Csanady, 1955) of

$$1 - \frac{1}{(1-n/2)(h_0\bar{u}/xv_g - 1) + 2} \qquad (5.40)$$

where n is one of Sutton's diffusion parameters. In practice the tilted plume model is only applicable in a well-mixed atmospheric layer, such as is typical of daytime adiabatic conditions within the lowest thousand meters.

The effect of horizontal wind-direction shear in the vertical becomes important as a diffusion mechanism if there is an initial distribution of particle sizes with height. With an initial cloud dimension of about 1000 m and particle fall velocities greater than 1 m/sec, the effect of turbulent diffusion on the ground deposition pattern can be neglected. The problem then becomes that of calculating particle trajectories using the appropriate fall velocity of each particle and the resultant wind vector of the atmospheric layer through which the particle falls. This technique as described by Kellogg, Rapp, and Greenfield (1957) has been applied primarily to the particle cloud resulting from surface nuclear-device detonations to calculate the fallout pattern for the first few hours after detonation.

5-3.2 Dry Deposition

5-3.2.1 Deposition Velocity. The observed fact that the deposition rate of small particles onto the ground can be greater than can be explained by the appropriate gravitational fall velocity has focused attention on nongravitational and nonprecipitation mechanisms, such as surface impaction, electrostatic attraction, adsorption, and chemical interaction. In analyzing the deposition of spores, Gregory (1945) concluded that the deposition rate was proportional to the immediate ground-level air concentration. Chamberlain (1953) defined the ratio of the deposition rate to the immediate ground-level air concentration as the deposition velocity, which, analogous to Eq. 5.39, can be stated as

$$\omega = v_d \bar{\chi}\,(x,y,0) \tag{5.41}$$

The interesting feature of such a formulation is that by using it as an experimental tool to compute v_d through the field or laboratory measurement of ω and $\bar{\chi}$, we can apply it to gases and vapors as well as to small particles. It in no way explains the physics of the deposition mechanism, but nevertheless it is a convenient way to express the whole complex and little-understood dry-deposition phenomenon.

5-3.2.2 Cloud Depletion. To account for the depletion of an airborne cloud because of dry deposition, Chamberlain (1953) modified Sutton's equation so that the original source term, Q_0', was replaced by an effective depleted-source term, Q_x'. Thus, for a continuous source at ground level, the depletion factor was expressed by Chamberlain as

$$\frac{Q_x'}{Q_0'} = \exp\left(-\frac{4 v_d\, x^{n/2}}{n \bar{u} \pi^{1/2}\, C_z}\right) \tag{5.42}$$

Using Eq. 5.41 and the modified Sutton equation, we can express the deposition rate per unit time per unit area for a source at ground level as

$$\omega = \frac{2 Q_0' v_d}{\pi \bar{u}\, C_y C_z x^{2-n}} \exp\left(-\frac{4 v_d\, x^{n/2}}{n \bar{u} \pi^{1/2}\, C_z}\right) \times \exp\left(-\frac{y^2}{C_y^2\, x^{2-n}}\right) \tag{5.43}$$

Chamberlain further expressed the depletion factor for the case of an elevated source. Culkowski (1958) has presented graphical solutions to these equations.

The generalized Gaussian diffusion formula (in the notation used in Chap. 3) can also be modified for cloud depletion. The depletion correction for a continuous elevated source can be derived as follows:

$$\omega(x,y) = v_d\, \bar{\chi}(x,y,0)$$
$$= \frac{v_d Q_x'}{\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right)\right] \tag{5.44}$$

where $\omega(x,y)$ is the surface deposition at (x,y) and Q_x' is the residual source at x meters downwind. The depletion of the source per unit distance is given by

$$\frac{\partial Q_x'}{\partial x} = -\int_{-\infty}^{\infty} \omega(x,y)\, dy$$
$$= -\left(\frac{2}{\pi}\right)^{1/2} \frac{v_d Q_x'}{\bar{u} \sigma_z} \exp -\left(\frac{h^2}{2\sigma_z^2}\right) \tag{5.45}$$

which can be rearranged as

$$\int_0^x \frac{dQ_x'}{Q_x'} = -\left(\frac{2}{\pi}\right)^{1/2} \frac{v_d}{u} \int_0^x \frac{dx}{\sigma_z \exp(h^2/2\sigma_z^2)} \tag{5.46}$$

If $Q_x' = Q_0'$ at $x = 0$, then

$$\ln \frac{Q_x'}{Q_0'} = -\left(\frac{2}{\pi}\right)^{1/2} \frac{v_d}{\bar{u}} \int_0^x \frac{dx}{\sigma_z \exp(h^2/2\sigma_z^2)} \tag{5.47}$$

and therefore

$$\frac{Q_x'}{Q_0'} = \left[\exp \int_0^x \frac{dx}{\sigma_z \exp(h^2/2\sigma_z^2)}\right]^{-(2/\pi)^{1/2} v_d/\bar{u}} \tag{5.48}$$

Since σ_z is not generally available as an analytical function of x in the generalized Gaussian form, the integral expression in Eq. 5.48 was evaluated numerically using the experimentally derived values of $\sigma_z(x)$ given by Hilsmeier and Gifford (1962). Figure 5.5 shows the depletion fraction, (Q_x'/Q_0'), as a function of distance from the source, diffusion category (in terms of Pasquill types or the corresponding values of σ_θ as given in Chap. 4, Sec. 4-4.4), height of release, a deposition velocity of 1 cm/sec, and a mean wind speed of 1 m/sec. To obtain depletion fractions for other deposition velocities and wind speeds, we may use the expression

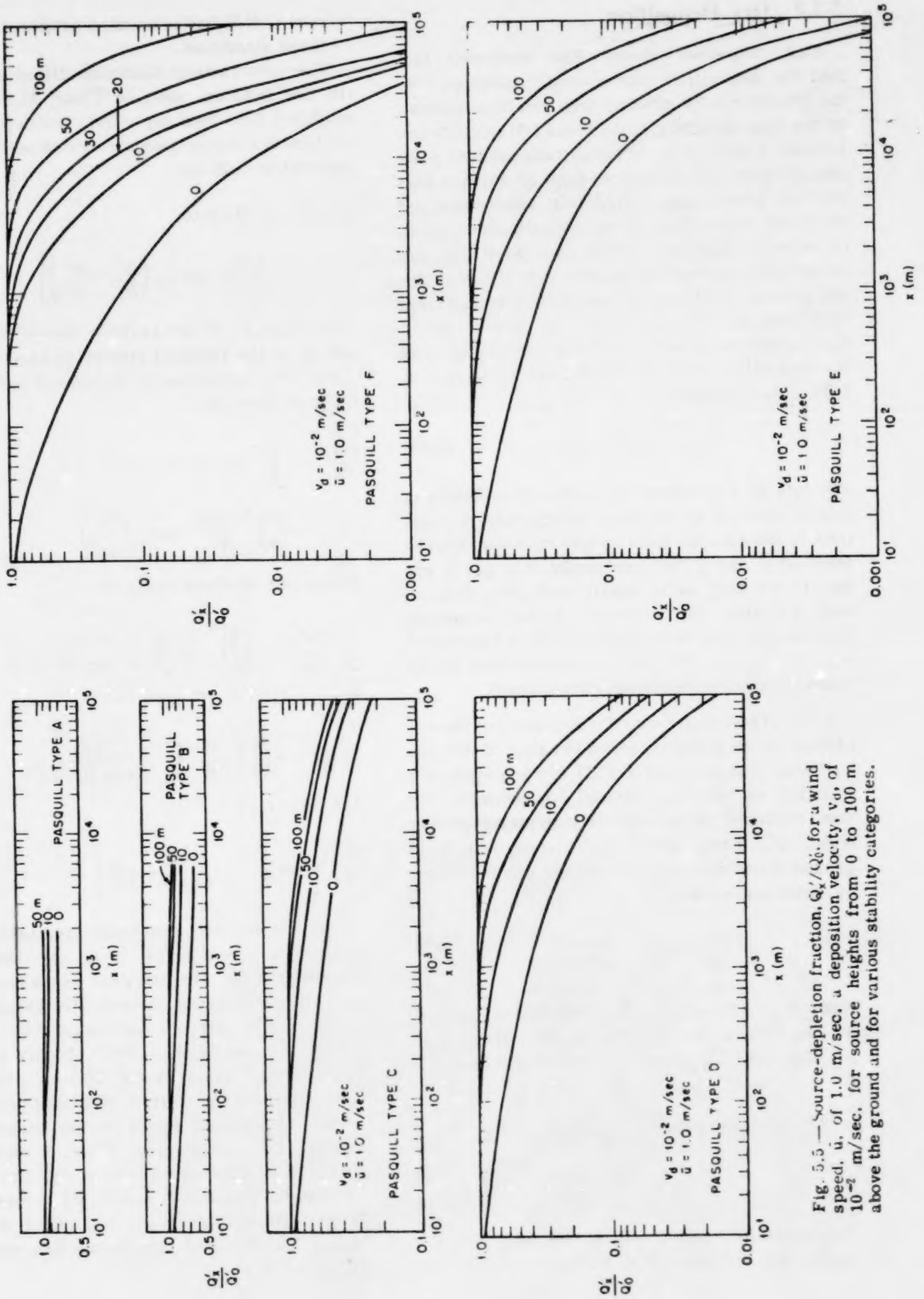

Fig. 5.5 — Source-depletion fraction, Q'_x/Q'_0, for a wind speed, $\bar{u}$, of 1.0 m/sec, a deposition velocity, v_d, of 10^{-2} m/sec, for source heights from 0 to 100 m above the ground and for various stability categories.

$$\left(\frac{Q'_x}{Q'_0}\right)_2 = \left(\frac{Q'_x}{Q'_0}\right)_1^{\bar{u}_1 v_{d_2}/\bar{u}_2 v_{d_1}} \qquad (5.49)$$

where the subscript 1 refers to values found in Fig. 5.5 and the subscript 2 refers to the desired values. Thus, for example, to find the depletion fraction at a distance of 10^4 m for a source 50 m high, a $\bar{u}_2$ of 1 m/sec, a v_d of 0.1 cm/sec, and a type F diffusion category, first find, in Fig. 5.5, the value of $(Q'_x/Q'_0)_1$ for $h = 50$ m, $x = 10^4$ m, $\bar{u} = 1$ m/sec, and $v_d = 1$ cm/sec: $(Q'_x/Q'_0)_1 = 0.50$. Now substitute this value in Eq. 5.49.

$$\left(\frac{Q'_x}{Q'_0}\right)_2 = (0.50)^{0.1} = 0.93$$

The Chamberlain and the generalized Gaussian depletion models assume that the shape of the concentration profile in the vertical is unaltered by deposition. In an approach suggested by Calder (1961), K theory diffusion equations (see Chap. 3, Sec. 3-2.1.2) were used to describe the effect of deposition on a plume. In models of this type, the reduction of concentration caused by removing material from the cloud is not distributed evenly through the depth of the cloud but depends upon the profile of vertical mixing. Therefore the shape of the vertical profile of concentration will change as the computation proceeds. Smith (1962a) schematically illustrates the effect for a case where $h = 0$, $v_g = 0$, $v_d > 0$, and the exchange coefficient is constant with height. The net result is a more rapid depletion of the bottom portion of the plume; so downwind from the source the height of the maximum concentration is above the surface and increases in the downwind direction. Definitive field measurements to evaluate the statistical depletion model and the K-theory depletion model are not yet available. Computations show that the statistical models (Eqs. 5.42 and 5.48) give higher depletion factors than the K-theory models under stable conditions.

5-3.2.3 Deposition Measurements. Among the important measurements of the deposition of radioactive vapors and aerosols are the pioneering efforts of Chamberlain (1960) at Harwell. He was concerned with the fission products formed in reactors or by nuclear detonations. The isotope ^{131}I was one of the more important fission products studied. Although liberated as a vapor, ^{131}I is thought also to be adsorbed on condensation nuclei which are too small to have an appreciable gravitational settling velocity but which, nevertheless, deposit on surfaces under electrostatic, chemical, and other physical forces. Chamberlain's ^{131}I-vapor-release experiments were conducted both in the wind tunnel and in the free atmosphere and included simultaneous air concentration and deposition measurements on natural and simulated leaves and grass and on filter paper.

Recently, a series called Controlled Environmental Radioiodine Tests (Hawley, Sill, Voelz, and Islitzer, 1964) was conducted at the National Reactor Testing Station in Idaho to trace the radioiodine through the air–vegetation–cow–milk–human chain. The field results of both the Harwell and Idaho tests are summarized in Table 5.9a, which gives the existing meteorological conditions and the computed (from Eq. 5.41) deposition velocities for various collection surfaces. Similar results on the deposition of ^{131}I were obtained by Convair (1959, 1960) from the Fission-products Field Release Test I held in Idaho (NRTS) and Test II held in Utah (Dugway). Results are summarized in Table 5.9b. Chamberlain (1959) further computed an ^{131}I deposition velocity averaging 0.4 cm/sec on grass for the Windscale accident; Islitzer (1962) computed 0.2 cm/sec on sagebrush for the SL-1 accident, which occurred in the winter.

From these results one would conclude that the dry-deposition velocity of ^{131}I ranges over an order of magnitude and is dependent, to a large extent, upon the characteristics of the vegetation and ground surface. It is not clear if or how wind speed, thermal stability, or atmospheric turbulence affects the velocities. It is also possible that downwind distance has an effect because of a physical change in the iodine, for example, from a vapor to an aerosol. At present, without really having any information on the physical processes involved in the dry deposition of ^{131}I upon natural surfaces, a value of 2.0 cm/sec for grass or water surfaces appears appropriate as an average maximum, and somewhat smaller values ranging down to 0.5 cm/sec, for soil and snow surfaces.

The Convair (1959, 1960) studies essentially involved the release and downwind measurement of various radioactive isotopes from irradiated metallic reactor fuel elements, including isotopes of iodine, cesium, ruthenium,

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Table 5.9a — SUMMARY OF ^{131}I DEPOSITION FIELD EXPERIMENT RESULTS*

	Harwell tests							Idaho tests		
	1	2	3	4	5	6	7	I	II	Snow
Deposition velocity, cm/sec										
Grass	1.9	2.6	1.8	3.7	1.7	1.8	1.1	0.6	1.0	
Soil								0.5	0.4	
Snow										0.2
Carbon								0.6	0.7	0.9
Clover leaves			1.3	0.9	0.5		0.3			
Paper leaves			2.0	1.5	1.0		0.6			
Filter paper	0.6	0.7	0.9	0.6	0.3					
Sticky paper								0.2	0.1	0.6
Wind speed, m/sec	5.2	1.3	5.2	1.1	1.6	2.3	3.9	7.1	9.3	6.0
Friction velocity, cm/sec	18	35	18	38	15	20	26	61	69	50
Roughness length, cm	2.8	1.5	1.2	2.4	2.4	5.0	1.0	3.1	1.5	2.1
Downwind distance, m	15	20	20	20	20	100	100	300	375	340
Grass cover, g/m^2	500	200	200	420	420	610	420	153	246	Snow cover
Stability	Lapse	Neutral	Lapse	Lapse	Neutral	Lapse	Neutral	Lapse	Lapse	Stable

*Chamberlain, 1960, and Hawley, Sill, Voelz, and Islitzer, 1964.

Table 5.9b — SUMMARY OF CONVAIR ^{131}I FIELD RELEASE TESTS*

	E	F	H	1	2	3	4	5	6	10	11
Deposition velocity, cm/sec											
Grass				2.1†						1.2‡	
Soil	0.5	1.4	0.5								
Sticky paper	1.1	0.7	1.5	0.4	0.3	0.1	0.2	0.2	0.3	0.2	0.6
Water	1.8†	2.3†	1.1†								
Wind speed, m/sec	6.8	5.3	1.0	5.6	4.2	3.2	2.4	4.4	2.7	2.6	4.4
Downwind distance, m	1,600	1,600	1,600	32,000	1,000	1,000	1,000	1,000	1,000	1,000	16,000
Stability	Lapse	Lapse	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable

*Convair, 1959, 1960.

†Downwind distance of 2000 m.

‡Downwind distance of 1000 m or less.

zirconium, cerium, niobium, and tellurium for which deposition-velocity calculations were made. Meteorological conditions included both adiabatic and stable lapse rates, and measurements of ground deposition and air concentrations were made to distances of 3200 m. Some sticky-paper measurements were made out to 3.2×10^4 m. All particles were less than 10 μ in diameter. Table 5.10 summarizes the deposition-velocity calculations. Note that these values are averages and that there is considerable scatter in the data which cannot be explained by the meteorological parameters that were measured. For example, the average deposition velocity of 0.2 cm/sec for ^{137}Cs on a grass surface was computed from 21 values ranging from 0.04 to 0.4 cm/sec.

Table 5.10 — SUMMARY OF CONVAIR RADIONUCLIDE FIELD RELEASE TEST DEPOSITION VELOCITIES

	Deposition velocities, cm/sec			
	Water	Soil	Grass	Sticky paper
^{137}Cs	0.9 (5)*	0.04 (15)	0.2 (21)	0.2 (117)
^{103}Ru	2.3 (9)	0.4 (16)	0.6 (20)	0.4 (98)
^{95}Zr, ^{95}Nb	5.7 (6)	2.9 (6)		1.4 (10)
^{141}Ce				0.7
^{127}Te, ^{129}Te				0.7 (8)

*Number in parentheses indicates the number of determinations.

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Another technique used in calculating deposition velocities is material-balance measurements such as performed by Islitzer and Dumbauld (1963) in their fluorescent-particle studies. The technique involves the determination of the mass flux of material through a vertical plane perpendicular to the mean wind direction. The downwind decrease of this flux is attributed to a material loss through deposition. Using uranin particles with a median diameter of 1 μ and a fall velocity of less than 10^{-2} cm/sec, Islitzer and Dumbauld computed deposition velocities of 0.2, 2.4, and 7.1 cm/sec for inversion, neutral, and lapse conditions, respectively, for the arid terrain in Idaho. From data presented by Simpson (1961), these authors also computed a value of 0.5 cm/sec for four stable cases with zinc sulfide submicron particles over similar terrain at Hanford, Wash. These and other deposition data are quoted in a summary article by Gifford and Pack (1962).

Two conclusions seem apparent from the available field data on the deposition of vapors and submicron particles, i.e., that chemically active materials such as ^{131}I deposit more readily than inactive materials such as ^{137}Cs or nonradioactive fluorescent particles and that vegetation surfaces such as grasses and bushes provide removal rates that are greater than bare surfaces. At present, however, what effects atmospheric transport and diffusion parameters have upon deposition or what effect more complex surfaces, such as buildings and forests, have upon deposition rates is not clear.

APPENDIX E

A SURFACE DEPLETION MODEL FOR DEPOSITION FROM A GAUSSIAN PLUME*

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A SURFACE DEPLETION MODEL FOR DEPOSITION FROM A GAUSSIAN PLUME*†

Thomas W. Horst
Atmospheric Sciences Department, Battelle, Pacific Northwest Laboratories,
Richland, WA 99352, U.S.A.

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Abstract—When the atmospheric diffusion of a material is described by the usual Guassian plume model, dry deposition of the contaminant onto the underlying surface is commonly accounted for by appropriately reducing the source strength, as originally proposed by Chamberlain. A more realistic model is developed which selectively depletes the Gaussian plume in the vicinity of the deposition surface rather than throughout the vertical extent of the plume as done in the source depletion model. This improved model is used to show that the source depletion model consistently overpredicts the surface air concentration and the deposition at downwind locations close to the source and, as a consequence, is biased in the opposite sense for locations far from the source. At all distances from the source, the source depletion model overestimates the total deposition between source and receptor and consequently underpredicts the amount of remaining airborne material. Quantitative comparisons are shown to aid the user in choosing, for his particular circumstances, between the less accurate source depletion model and the computationally more complex surface depletion model.

Dry deposition of an airborne material onto the underlying surface is of interest from two different standpoints. First of all, it can be an important sink for the material, reducing air concentrations (and consequent dry deposition) further downwind. In the case of a noxious substance this is beneficial to downwind receptors. However, dry deposition secondly is a mechanism for accumulation of the material on the ground and hence may be detrimental at the point of deposition. Since a high estimate for the deposition flux will be conservative at the point of deposition and, at the same time, nonconservative downwind of that point, modeling of the dry deposition process should be unbiased. However, it will be shown here that the source depletion model currently used for predicting deposition from the Gaussian plume is biased. This will be done by developing a surface depletion model which eliminates the artificial bias of the former model and by comparing the predictions of the two models. The biases of the source depletion model will be quantitatively delineated in order to provide a basis for choosing, in a specific situation, between the less accurate source depletion model and the computationally more complex surface depletion model.

THE DEPOSITION VELOCITY

The deposition of airborne material onto the underlying surface can be caused by a combination of mechanical processes (gravitational settling, turbulent and molecular diffusion, inertial impaction) and is often further complicated by electrical and chemical effects or the existence of heat and moisture fluxes normal to the deposition surface. In the absence of detailed microphysical measurements, the deposition flux F_d is usually assumed to be directly proportional to the local air concentration evaluated at a reference height z_d,

$$F_d(x,y) = v_d\chi(x,y,z_d). \qquad (1)$$

The constant of proportionality v_d has the dimensions of a velocity and has been appropriately named the deposition velocity. For common aerosols v_d can vary from about 10^{-4} to $10\,\text{cm}\,\text{s}^{-1}$, depending on specific properties of the particles, of the atmospheric structure, and of the deposition surface (Sehmel, 1975). Most of the results to be presented here, however, are parameterized only by the ratio of the deposition velocity to the mean windspeed, v_d/u, and this will be assumed to be independent of the horizontal coordinates. Since u in the lowest 100 m of the atmosphere is commonly in the range of 1–$10\,\text{m}\,\text{s}^{-1}$, v_d/u can vary from about 10^{-7}–10^{-1}.

SOURCE DEPLETION MODEL

The atmospheric diffusion process will be described by the standard Gaussian plume model for a nondepositing material, incorporating "reflection" of the material at the ground to insure conservation of mass. For that purpose we define a diffusion function $D(x,y,z,h)$:

$$D(x,y,z,h) \equiv \frac{u\chi(x,y,z)}{Q_0} = \frac{e^{-y^2/2\sigma_y^2}}{2\pi\sigma_y\sigma_z} \times \left\{\exp\left[\frac{-(h-z)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(h+z)^2}{2\sigma_z^2}\right]\right\}. \qquad (2)$$

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where $\chi(x, y, z)$ is the downwind air concentration due to a continuous source of constant strength Q_0 located at the point $(0, 0, h)$.* The coordinates x, y, z are oriented, respectively, in the direction of the mean wind u, horizontal and normal to u, and vertical and normal to u. The diffusion parameters σ_y and σ_z are the horizontal and vertical standard deviations of the assumed Gaussian plume.

The source depletion model (Van der Hoven, 1968), then, accounts for the loss of airborne material due to deposition by appropriately reducing the source strength as a function of downwind distance, i.e.

$$\chi(x, y, z) = Q(x)\frac{D}{u}(x, y, z, h). \tag{3}$$

Conservation of mass requires that:

$$\frac{\mathrm{d}Q(x)}{\mathrm{d}x} = -\int_{-\infty}^{\infty} v_d\chi(x, y, z_d)\,\mathrm{d}y = -\frac{v_d}{u}Q(x)\bar{D}(x, z_d, h), \tag{4}$$

where

$$\bar{D}(x, z, h) = \frac{1}{\sqrt{2\pi}\sigma_z}\left\{\exp\left[\frac{-(h-z)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(h+z)^2}{2\sigma_z^2}\right]\right\}. \tag{5}$$

Thus

$$Q(x) = Q_0\exp\left\{-\int_0^x \frac{v_d}{u}\bar{D}(\xi, z_d, h)\,\mathrm{d}\xi\right\}, \tag{6}$$

where Q_0 is the undepleted source strength at $x = 0$. Note that although the source depletion model correctly determines the deposition flux in terms of the air concentration near the surface $\chi(z = z_d)$, it also instantaneously distributes the effect of the deposition throughout the entire vertical extent of the plume. Retaining the Gaussian shape of the plume thus artificially enhances the vertical diffusion. The qualitative and quantitative results of this effect will be seen below.

SURFACE DEPLETION MODEL

A more realistic approach is provided by the surface depletion model. In the development of this model, advantage is taken of the fact that the linearity of the differential equation describing gradient diffusion allows the superposition of solutions such as equation (2) to account for a number of sources at different locations. The deposition flux to the surface is represented as a material sink, i.e. a source for downwind diffusion of a material deficit from the point of deposition. Thus deposition at the point $(\xi, \eta, 0)$ will effect a reduction of the air concentration at the downwind point (x, y, z) equal to:

$$[-v_d\chi(\xi, \eta, z_d)\,\mathrm{d}\xi\,\mathrm{d}\eta]\frac{D}{u}(x-\xi, y-\eta, z, 0), \tag{7}$$

where the bracketed quantity is an areal source strength due to deposition. The air concentration at any point can then be calculated as the sum of the nondepositing diffusion from the primary source at $(0, 0, h)$ plus the diffusion from all of the upwind surface sources which account for deposition,

$$\chi(x, y, z) = Q_0\frac{D}{u}(x, y, z, h) - \int_{-\infty}^{\infty}\int_0^x \frac{v_d}{u}\chi(\xi, \eta, z_d)\,D(x-\xi, y-\eta, z, 0)\,\mathrm{d}\xi\,\mathrm{d}\eta. \tag{8}$$

Given then that Q_0D/u is the solution to the convective diffusion equation without deposition, equation (8) is the exact solution to the same differential equation subject to the deposition velocity boundary condition, equation (1). This may be verified by direct substitution into the diffusion equation.

Equation (8) and the subsequent calculations can be considerably simplified if we consider the crosswind-integrated air concentration:

$$\bar{\chi}(x, z) = Q_0\frac{\bar{D}}{u}(x, z, h) - \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_0^x \frac{v_d}{u}\chi(\xi, \eta, z_d) \times D(x-\xi, y-\eta, z, 0)\,\mathrm{d}\xi\,\mathrm{d}\eta\,\mathrm{d}y. \tag{9}$$

Performing, in succession, the integrations over y and η yields:

$$\bar{\chi}(x, z) = Q_0\frac{\bar{D}}{u}(x, z, h) - \int_0^x \frac{v_d}{u}\bar{\chi}(\xi, z_d) \times \bar{D}(x-\xi, z, 0)\,\mathrm{d}\xi. \tag{10}$$

For comparison, a similar equation may be written for the source depletion model:

$$\bar{\chi}(x, z) = \left[Q_0 - \int_0^x v_d\bar{\chi}(\xi, z_d)\,\mathrm{d}\xi\right]\frac{\bar{D}}{u}(x, z, h). \tag{11}$$

This is equivalent to equations (3 and 6). Comparison of the variables upon which D is functionally dependent in equations (10 and 11) again emphasizes the artificial assumption of the source depletion model that deposition is a loss at the source $(0,0,h)$ rather than at the surface where it is actually occurring. The source depletion model, of course, is the easier model to apply since it retains the Gaussian distribution in the vertical and thus all effects of deposition are summarized in the single parameter $Q(x)/Q_0$. Further, equations (6) or (11) is much more economical to compute than equation (10) since the integrand of the

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* For a bouyant effluent, h is the effective source height.

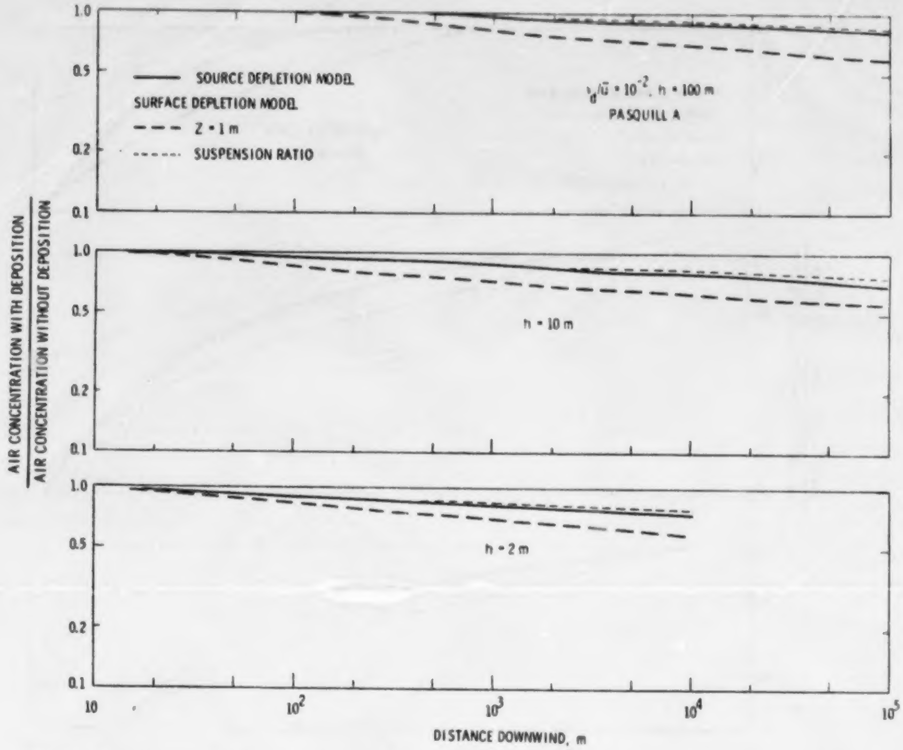

Fig. 1. Comparison between source depletion and surface depletion models for $r_a/u = 10^{-2}$ and unstable thermal stratification.

deposition integral is not a function of the receptor coordinate x.*

COMPARISON OF THE MODELS

Both models were applied to a variety of situations to assess the accuracy of the source depletion model relative to the surface depletion model and to provide information upon which to base a decision as to which model to use in a given situation. Some of the results of these calculations are shown in Figs. 1–4 which display, as a function of downwind distance from the primary source, the ratio between the air concentrations with deposition and without deposition as calculated by both the source depletion model and the surface depletion model. For the surface depletion model three ratios are shown: that of the air concentrations at a height of 1 *m*, z_d; at the source height, h; and vertically integrated over all heights. The latter curve, also called the suspension ratio, represents the fraction of the material which is still airborne or, subtracting from unity, the fraction deposited on the surface to that distance. As indicated in the model derivation, all three of these ratios are predicted for the source depletion model by the suspension ratio, $Q(x)/Q_0$. Calculations were made for three source heights: 2, 10, and 100 m, and for three atmospheric stability categories: unstable (Pasquill *A*), neutral (Pasquill *D*), and stable (Pasquill *F*), using the rural diffusion coefficients amalgamated by Briggs (1973). While these σ's, shown in Table 1, may already include the effects of deposition, they are entirely adequate for comparing the two deposition models. Note finally that the curves are parameterized with the ratio r_d/u. It can be shown from the equations presented above that the ratio between the air concentrations with and without deposition is a function only of the ratio r_d/u and not r_d and u independently.

Figures 1–3 present results for $r_d/u = 10^{-2}$, a case of moderately strong deposition, and for all combinations of thermal stability and source height. As discussed above, the assumptions of the source depletion model produce artificial vertical mixing of the plume. Since the vertical mixing due to real atmospheric processes decreases with increasing stability, the effects of the artificial mixing would be expected to become correspondingly more noticeable as the thermal stability increases. It is easily seen from Figs. 1–3 that

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* The surface depletion model requires 3.84 CDC CYBER 74-18 s to calculate the three functions displayed in the following figures for one combination of h, r_d/u and stability and three decades of downwind distance. The source depletion model required only 0.17 s for the same task and it could have been done even more economically.

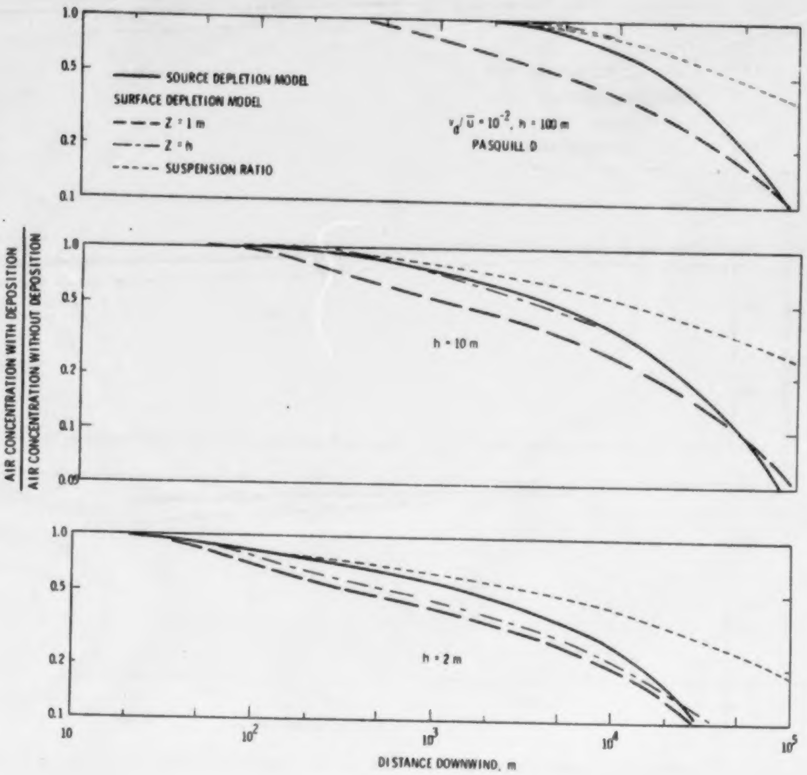

Fig. 2. Comparison between source depletion and surface depletion models for $r_d/u = 10^{-2}$ and neutral thermal stratification.

the differences between the two models do increase with increasing stability. Further, it is expected that the differences would decrease as the deposition decreases since the models are identical in the limit of $r_d = 0$. This is demonstrated by comparing Fig. 4 for $r_d/u = 10^{-3}$ and three combinations of height and stability with the corresponding cases in Figs. 1–3 for $r_d/u = 10^{-2}$. For the source depletion model it can be shown (Van der Hoven, 1968) that the relationship between the suspension ratios for different values of r_d/u is:

$$[Q(x)/Q_0]_a^{(r_d/u)_b} = [Q(x)/Q_0]_b^{(r_d/u)_a}. \quad (12)$$

Figures 1–4 show that the functional dependence of the surface depletion model on r_d/u is equally strong.

As expected, the surface depletion model in general predicts smaller air concentrations at z_d than does the source depletion model. This is due to the fact that it realistically duplicates the actual physical situation by selectively depleting the portion of the plume adjacent to the surface rather than the entire vertical extent of the plume. Consequently, the surface depletion model also produced less deposition close to the source because the material deficit near the surface insulates the bulk of the plume from the deposition surface. Thus, as shown by the suspension ratio, the surface depletion model always has a greater total quantity of airborne material. At large distances downwind of the source this has the effect of raising the near-surface air concentration of the surface depletion model until in some cases it eventually equals and surpasses that of the source depletion model. This occurs likewise for the dry deposition. These effects are best seen in Fig. 3, which presents the most extreme surface model source model differences.

Table 1. Formulas for the determination of σ_z from Briggs (1973)(x and σ_z m)

Stability class	σ_z
A	$0.20x$
B	$0.12x$
C	$0.08x(1 + 2{*}10^{-4}x)^{-1/2}$
D	$0.06x(1 + 1.5{*}10^{-3}x)^{-1/2}$
E	$0.03x(1 + 3{*}10^{-4}x)^{-1}$
F	$0.02x(1 + 3{*}10^{-4}x)^{-1}$

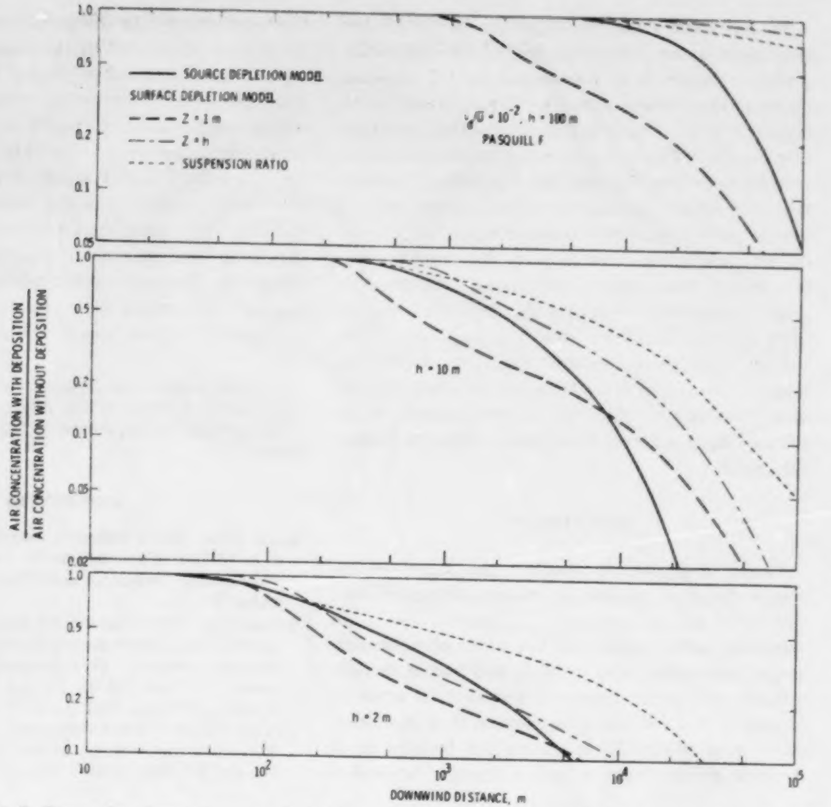

Fig. 3. Comparison between source depletion and surface depletion models for $v_d/u = 10^{-2}$ and stable thermal stratification.

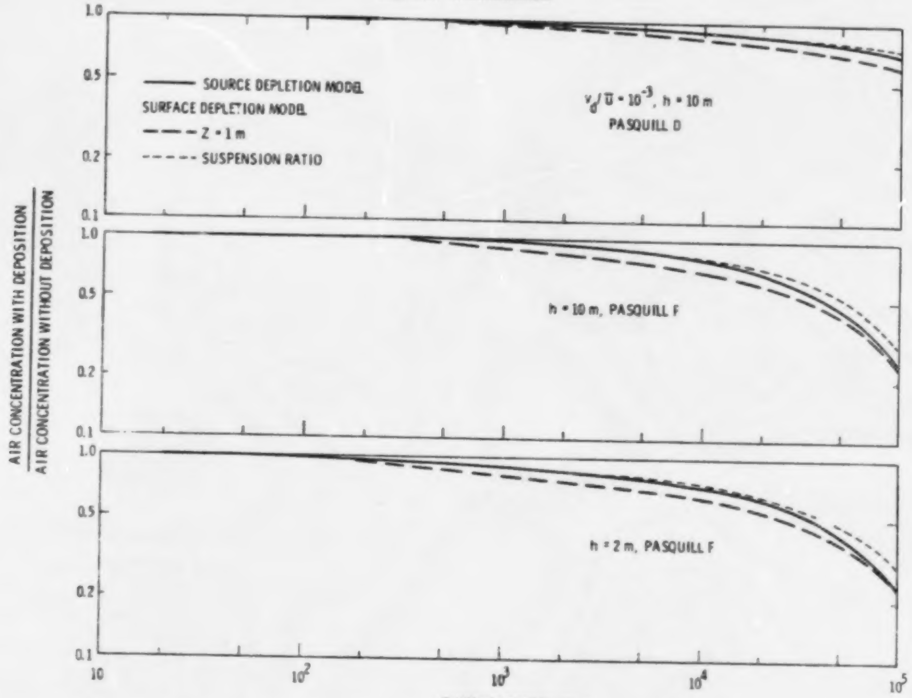

Fig. 4. Comparison between source depletion and surface depletion models for $v_d/u = 10^{-3}$.

Figures 2 and 3 also show the ratio of the air concentration at source height as predicted by the surface depletion model to that predicted by the Gaussian plume model without deposition. This variable is not shown in Figs. 1 and 4 due to the tight grouping of the curves. The only consistent relationship to be seen between this variable and the others shown is that the source height air concentration ratio is always greater than the reference height air concentration ratio as also calculated by the surface depletion model. This is due to the vertical concentration gradient required to support the deposition flux. In most cases it is also less than the suspension ratio; but since circumstances can always be found, e.g. large release height and strong stability, in which the deposition is not effectively communicated to the release height, it can also be greater than the suspension ratio.

CONCLUSIONS

Figure 3 graphically displays the biases of the source depletion model: an overprediction of total deposition and a consequent underprediction of the remaining airborne material. For a case of moderately strong deposition, $v_d/u = 10^{-2}$, and stable thermal stability the source depletion model is in error by factors of 3–4 for some parameters at a downwind distance of 10 km. These factors can become much larger at greater distances and for stronger deposition. Correspondingly, the differences between the models are sharply attenuated by decreasing v_d/u or decreasing the thermal stability. Figure 4 shows the worst cases calculated for $v_d/u = 10^{-3}$ from the set of three release heights and three stabilities. The errors of the source depletion model are only 10–20%. Similarly for $v_d/u = 10^{-2}$ and Pasquill A stability, the worst error is about 35%. Thus the source depletion model can be entirely adequate for a situation involving low deposition and grossly in error for a case of high deposition. The user must determine where the dividing line lies between these two extremes by carefully considering his own situation and requirements.

Acknowledgement—This research benefited from discussions with C. E. Elderkin who originally proposed the idea of accounting for deposition by diffusion of a material deficit.

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APPENDIX F

CALCULATION OF CRITICAL AMBIENT LEAD CONCENTRATION BELOW WHICH THE NAAQS WILL BE ATTAINED BY 1982 DUE TO MOBILE SOURCES IN URBANIZED AREAS

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ASSUMPTIONS

1. A NAAQS for lead of 1.5 μg/m^3, maximum quarterly mean to be attained by 1982.

2. No change in urbanized areas of traffic (VMT), average vehicle speeds, or stationary source emissions between 1976 and 1982.

3. No change in the level of control on stationary sources in urbanized areas between 1976 and 1982.

4. No reduction in lead emissions between 1976 and 1982 from vehicles other than automobiles.

5. Automobile lead emissions contributed 90 percent of total lead emissions in urbanized areas in 1976.

6. A background lead concentration originating from outside the urbanized area of 0.1 μg/m^3, quarterly mean, in 1982.

7. Air quality concentrations vary proportionally with emissions; also, assumptions normally associated with proportional modeling apply.

CALCULATION

The proportional model relating air quality concentrations to reductions needed to attain a standard is given by the following equation:

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$$R = \frac{A_B - S}{A_B - B} \qquad (1)$$

Where: R = the proportional reduction in emissions needed (non-dimensional decimal);

A_B= the air quality concentration in the base year ($\mu g/m^3$);

S = the level of the air quality standard ($\mu g/m^3$);

B = the level of the background concentration ($\mu g/m^3$).

Equation (1) can be expressed in terms of the critical air quality concentration in the base year as follows:

$$A_B = \frac{S - B\,R}{1 - R} \qquad (1A)$$

The emission reduction obtained in an urbanized area from 1976 to 1982 can be expressed as follows:

$$R = \frac{E_{76} - E_{82}}{E_{76}} \qquad (2)$$

Where: E_{76} = lead emissions in the area in 1976;

E_{82} = lead emissions in the area in 1982.

Lead emissions can be separated into two classes, automobile (E_A) and non-automobile (E_N), where:

$$E_{76} = E_{A,76} + E_{N,\,76} \qquad (3)$$

and

$$E_{82} = E_{A,82} + E_{N,76}{}^{*}. \qquad (4)$$

From assumption No. 5,

$$E_{A,76} = 0.9E_{76}$$

or

$$E_{76} = 1.11\ E_{A,\,76}. \qquad (5)$$

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*Since non-automobile source emissions are assumed to remain constant.

Therefore,

$$E_{N,76} = 0.1\ E_{76}$$

$$= 0.1(1.11\ E_{A,76})$$

$$E_{N,76} = 0.11\ E_{A,76} \tag{6}$$

The ratio of automobile emissions in 1982 and 1976 is the same as the ratio of the automobile emission rates for the two years, or,

$$\frac{E_{A,82}}{E_{A,76}} = \frac{e_{82,s}}{e_{76,s}}\ , \tag{7}$$

where $e_{82,s}$ = emission rate for 1982 and speed s (g/day);

$e_{76,s}$ = emission rate for 1976 and speed s (g/day);

The emission rate from automobile sources as area sources is calculated by the following equation:

$$e_{n,s} = \frac{a_s\ Pb_n V}{f_{n,s}}\ , \tag{8}$$

where: $e_{n,s}$ = emission rate for calendar year n and speed s (g/day);

a_s = percentage of lead burned that is exhausted (nondimensional; expressed as a decimal);

Pb_n = probable pooled average lead content of gasoline in year n (g/gal);

V = vehicle-miles travelled daily (vehicle-miles/day);

$f_{n,s}$ = average fleet fuel economy for calendar year n and speed s (vehicle-miles/gal).

The terms a_s and V are assumed to remain constant from 1976 to 1982. Using values of Pb_n and $f_{n,s}$ from the draft lead guideline, (interpolating where necessary and using the average fleet speed), for 1976, Pb_n = 1.4 g/gal and $f_{n,s}$ = 13.0 miles/gal; for 1982, Pb_n = 0.34 g/gal and $f_{n,s}$=17.9 miles/gal.

Substituting these into equation (8), we obtain

$$e_{76,s} = \frac{(1.4 \text{ g/gal})\ a_s V}{13.0 \text{ mi/gal}}$$

$$= 0.108\ (a_s V) \text{ g/mile}$$

and

$$e_{82,s} = \frac{(0.34 \text{ g/gal})\ a_s V}{17.9 \text{ m}}$$

$$= 0.019\ (a_s V) \text{ g/mile.}$$

Substituting these results into equation (7), we obtain

$$\frac{E_{A,76}}{E_{A,76}} = \frac{0.019\ (a_s V) \text{ g/mile}}{0.108\ (a_s V) \text{ g/mile}}$$

$$= 0.176,$$

or

$$E_{A,82} = 0.176\ E_{A,76}.$$

Substituting this expression and equation (6) into equation (4) yields

$$E_{82} = (0.176\ E_{A,76}) + (0.11\ E_{A,76}).$$

$$= 0.286\ E_{A,76}$$

Substituting this result and equation (5) into equation (2) yields

$$R = \frac{E_{76} - E_{82}}{E_{76}}$$

$$= \frac{(1.11\ E_{A,76}) - (0.286\ E_{A,76})}{1.11\ E_{A,76}}$$

$$= 0.74.$$

Substituting this into equation (1A) yields the critical air quality concentration:

$$A_{76} = \frac{1.5\ \mu g/m^3 - 0.1\ \mu g/m^3\ (0.74)}{1-0.74}$$

$$= 5.5\ \mu g/m^3.$$

APPENDIX G

ROLLBACK MODELING -- BASIC AND MODIFIED

Reprinted from de Nevers, Noel, and Roger Morris, Rollback Modeling -- Basic and Modified. Paper No. 73-139, presented at the Annual Meeting of the Air Pollution Control Association, June 24-28, 1973, Chicago, Illinois.

No. 73-139

Abstract of a Paper to be Presented to the APCA
Meeting, June 24-28, 1973, Chicago, Illinois

Rollback Modeling - Basic and Modified

by

Noel de Nevers* and Roger Morris
Environmental Protection Agency

The body of information presented in this paper is directed to those interested in the formation and evaluation of emission control strategies for air quality standard achievement and maintenance in urban areas. The paper will be of particular interest to those charged with the selection and use of models for relating urban emissions to expected air quality.

The "rollback" or "proportional" model is widely used in pollution control calculations and included in the guidelines for preparing and evaluating state implementation plans. Its basis and limitations are not widely known or understood. In this paper the basis and limitations of rollback are listed and discussed. In its simple form, it is only truly applicable to a very narrow range of pollution control situations.

Four modified forms of rollback are derived and presented. The first of these extends basic rollback to multiple categories of sources, which may experience differing rates of growth and degrees of control. The second modified form extends this multiple-source version to include the effects of average stack heights for the various categories. The third model includes the radial distance from source to receptor, and the fourth model adds wind direction frequency.

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*Present affiliation: Department of Chemical Engineering, University of Utah

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All of these rollback models including simple rollback are shown to be derivable from the same, simple formula which is

$$\frac{(c_i - b)_{future}}{(c_i - b)_{base}} = \frac{\Sigma[k_{ij}\ e_j]_{future}}{\Sigma[k_{ij}\ e_j]_{base}} \qquad (1)$$

where c_i is the pollutant concentration at point i

b is the background concentration

e_j is the emission rate of category j

and k_{ij} is the contribution of a unit emission rate from category j to concentration at point i.

Each model differs from the others only in the number of categories into which the area emissions are divided and in the method of estimation of k_{ij}.

The principal conclusion is that "rollback" modeling should begin with equation (1) and proceed to the form that is justified by plausible assumptions and data availability. Simple rollback would seldom be used if this procedure were adopted. In most cases the third or fourth model would be more appropriate. These latter models are significant steps from simple rollback in the direction of the more advanced "diffusion models" which are often used in air quality modeling. They are clearly much less sophisticated than the large computer models now in use but more sophisticated than the simple rollback formula used for the state implementation plans. Thus, they may play a useful role as intermediate tools between the very simple, hand-calculated rollback formula and the more advanced and complex models.

MODELS AND MODELING

A model is an intellectual construct, which represents reality, and can be manipulated to predict the consequences of various actions. In recent years there has been some controversy over what is a model, and whether we ought to base air pollution regulations, which have the force of law, on models. According to the above definition, simple rollback (1) is a model, and regulations based on it (e.g., State Implementation Plans) are ultimately based on modeling. As this paper shows, rollback is a very simple model, probably the simplest air pollution model which can be used to make quantitative predictions. Considerable effort has gone into more complex models (normally called "diffusion models"), (2-5) whose function is to do the same thing as rollback, but with greater detail and accuracy, and with greater confidence in the result.

In any modeling effort one is constantly making a tradeoff between simplicity and accuracy. The true physical world is complex; we will not have models of total accuracy unless they are complex. An accurate model cannot be simple; a simple model cannot be accurate. We all strive to produce a modeling breakthrough like Copernicus did, when his much simpler heliocentric model of the solar system replaced the extremely complex Ptolemaic geocentric model, and produced more accurate results, i.e., more accurate predictions of the observed positions of the planets. So far no one has made such a breakthrough in air-quality modeling, so our current choices are complex models of fair accuracy, and simple models (like rollback) with lesser accuracy.

SIMPLE ROLLBACK (OR PROPORTIONAL) MODELING

The simplest and most intuitively obvious air pollution model is the qualitive one which says "If you reduce emissions, the air will become cleaner." This is the intellectual basis for all air pollution control regulations enacted until the late 1950's. It fits logically with the "maximum technology" approach, which simply requires all emitters to use "good engineering practice" in controlling pollutant emissions. By the late 1950's it became clear that in Southern California emissions from automobiles would have to be reduced beyond what then constituted "good engineering practice." To provide a basis for setting numerical standards, those active in that area developed the next level of air pollution model, which in its current form is called "simple rollback" or "proportional modeling."

In its most basic form rollback assumes that the concentration of any long-lived pollutant at any point is equal to the background concentration of that pollutant plus some linear function of the total emission rate of that pollutant in the area which influences the concentration at that point,

$$c_i = b + ke \tag{1}$$

where c_i is the ambient concentration of one specific pollutant at the i-th point, normally expressed in $\mu g/m^3$,

b is the irreducible background concentration of that pollutant for air uninfluenced by those nearby emitters which influence the concentration at point i, normally in $\mu g/m^3$,

k is a proportionality factor, which takes into account the meteorology, location of all emitters as seen from point i, and the other factors which influence the source-receptor interaction at that point. Its normal dimensions are ($\mu g/m^3$)/(gm/sec) and

e is the total emission rate of all emitters of that pollutant within the geographical area modeled, normally a city or metropolitan area; its normal dimensions are gm/sec.

For standard-setting purposes one proceeds by solving Eq. (1) for e, and defining the allowable emission rate,

$$e_{allowable} = (c_{allowable} - b)/k \qquad (2)$$

where the "allowable" subscript indicates the allowable emission rate is that which produces the allowable concentration at the point of interest. If we further assume that $c_{allowable}$ is the applicable ambient air quality standard for that specific pollutant, which we will call std, then we may write

$$e_{allowable} = (std - b)/k \qquad (3)$$

To solve this equation we need the value of k. From the discussion of Eq. (1) it is clear that k is not a single constant for a given city, but is a function of location within the city; it is higher for points near major emission sources than those far from them. In American air pollution law the standards must be met at every point, so we need the value of k corresponding to the highest value of c. Solving Eq. (1) for this value we find

$$k = (c_{max} - b)/e \qquad (4)$$

Here c_{max} is the highest pollutant concentration in the region of interest. Substituting the value of k from Eq. (4) into Eq. (3) we find

$$e_{allowable} = e(std - b)/(c_{max} - b) \qquad (5)$$

Figure 1 illustrates the relations in Eq. (5).

The next manipulation commonly made is to write

$$e_{\text{allowable}} = \text{(population)(allowable emissions per unit of population)} \qquad (6)$$

Here the appropriate population may be a population of residences or automobiles, or industries, etc. Similarly one replaces the e in Eq. (5) with

$$e = (\text{population at time of measuring } c_{\text{max}})(\text{emission per unit of population at time of measuring } c_{\text{max}}).$$

Dividing both sides of Eq. (5) by e, and making these substitutions, we find

$$\frac{\text{(population)(allowable emissions per unit of population)}}{(\text{population at time of measuring } c_{\text{max}})\ (\text{emissions per unit of population at time etc.})}$$

$$= (\text{std} - b)/(c_{\text{max}}) \qquad (8)$$

We then simplify this by defining

$$\text{gf} = \text{growth factor} = \frac{\text{(population)}}{(\text{population at time of measuring } c_{\text{max}})} \qquad (9)$$

and

$$\text{ef} = \text{emission factor} = \frac{\text{(allowable emission per unit of population}}{(\text{emissions per unit at time of measuring } c_{\text{max}})} \qquad (10)$$

Substituting these in Eq. (8) and solving for ef we find

$$\text{ef} = (\text{std} - b)/\text{gf}\ (c_{\text{max}} - b) \qquad (11)$$

Finally we define the required percent reduction in emissions per unit of population as

$$\begin{aligned} R &= 100\%\ (1-\text{ef}) \\ &= 100\% \left[1 - \frac{(\text{std} - b)}{\text{gf}(c_{\text{max}} - b)}\right] \end{aligned}$$

$$= 100\% \frac{(gf \cdot c_{max} - std + b\,(1 - gf))}{gf \cdot c_{max} - gf \cdot b} \qquad (12)$$

Eq. (12) (which is the basic result of the linear assumption of Eq. (1)) appeared too complex to the early workers in air pollution, so they simplified it by setting the b (1 - gf) in the numerator to zero and changing the gf.b in the denominator to a simple b. (This is equivalent to changing the denominator of Eq. (11) from gf (c_{max} - b) to (gf.c_{max} - b). Making these changes we find

$$R = 100\% \frac{(gf \cdot c_{max} - std)}{(gf \cdot c_{max} - b)} \qquad (13)$$

which is the "simple rollback" or "proportional model" equation used in previous work into auto emission standard setting, and which is specified in the guidelines for preparing State Implementation Plans (1).

One may most easily see the effect of this simplification by constructing the ratio

$$\frac{(1-R)_{Eq.\ (12)}}{(1-R)_{Eq.\ (13)}} = \frac{(std - b)/gf(c_{max} - b)}{(std - b)/(gf \cdot c_{max} - b)} = \frac{gf \cdot c_{max} - b}{gf \cdot c_{max} - gf \cdot b} \qquad (14)$$

If we divide both top and bottom of the right hand side of Eq. (14) by c_{max} we see that the ratio of (1-R) for the complete equation to (1-R) for the simplified equation depends on gf and (b/c_{max}). Figure 2 shows the values of this function for several values of gf. From it we see that if gf is one the two equations give the same value, and if b is zero the two equations give the same value. For all other values of gf and b/c_{max}, (1-R)for the complete equation is larger than (1-R) for the simplified equation, indicating that the simplified equations leads to a more stringent set of standards than the complete equation. As long as b/c_{max} is small the ratio is small, but as b/c_{max} becomes greater than about 0.3, the ratio begins to grow rapidly, becoming infinite for b/c_{max} equal to one. Thus, for areas in which growth is low, or background is small compared to the highest measured concentration, this simplification makes a small change, and always makes it in favor of more restrictive standards. For large values of gf and in areas where the background is a large fraction of the largest measured concentration, this simplification makes the standards much more restrictive than the complete equation.

FIRST NUMERICAL EXAMPLE

To illustrate how this equation works (and to compare it with subsequent equations) we will work a numerical example here. This example will be expanded and continued in further parts of the paper. The example considers "pollutant x" in "hypothetical city." The data used in this part of the example and the further parts are all given in Table 1.

For this example,

$$\begin{aligned} c_{max} &= 200\ \mu g/m^3 \\ b &= 10\ \mu g/m^3 \\ gf &= 1.30 \\ std &= 100\ \mu g/m^3 \end{aligned}$$

Thus, using Eq. (13) (simple rollback) we have

$$R = 100\% \frac{(1.3 \cdot 200 - 100)}{(1.3 \cdot 200 - 10)} = 100\% \cdot \frac{160}{250} = 64.0\%$$

i.e., to meet the standard with this growth factor, all emitters must reduce their emission rate by 64%. If we had used Eq. (12) (the complete form of rollback) we would have found,

$$R = 100\% \frac{(1.3 \cdot 200 - 100 + 10(1 - 1.3))}{(1.3 \cdot 200 - 1.3 \cdot 10)} = \frac{100\% \ (157)}{247} = 63.6\%$$

In this case, the simple rollback formula yields a result 0.6% greater than the complete equation, i.e., the uniform emission reduction required, as calculated by the simplified equation, is 0.6% greater than necessary.

THE LIMITATIONS OF SIMPLE ROLLBACK

Simple rollback (Eq. (13)) is widely used because it is simple and easily understood, and because it requires very little input data. It has some severe limitations, which are discussed here.

1. It is a purely theoretical model, for which no experimental verification has ever been attempted in a metropolitan area, and which can probably never be subjected to experimental verification in a metropolitan area. The reason that the experimental verification for a metropolitan area has not been attempted, and probably never will be, is that the relation between concentration and emission rate (Eq. (1)) assumes that all other factors remain unchanged, including the spatial distribution of emissions. Thus, to test the equation one would have to reduce the emission of each and every emission source in the area by the same percentage. For practical reasons this does not seem possible in a metropolitan area.

This is not as severe a shortcoming as it might appear, because the theoretical basis of Eq. (1) is quite plausible. However, it could be wrong in several ways. If emissions influence climate (e.g., by changing turbidity of the atmosphere) then the linear assumption in Eq. (1) would probably prove false. If pollutant disappearance (e.g., by agglo meration or photochemical reaction) is not a linear function of pollutant concentration (which it probably is not) then we would expect a non-linear relationship between emissions and concentration. There are probably other causes which could lead to non-linearity in this relation as well.

2. The application of the equation requires that we know the value of c_{max}, the highest concentration of pollutant in the area. In general usage one substitutes the highest observed concentration $(c_{max})_{obs}$ for c_{max}. These two will only be the same if one of the air quality measuring stations is located at the point of maximum concentration. This assumption is non-conservative, i.e., leads to less stringent regulations than would be used if the true value of c_{max} were known.

3. The growth factor (gf) as used here assumes that all emission rates will grow, without changes in other significant parameters (e.g., distribution of emissions, city size, stack heights, etc.). If the value used here is the projected increase, for example, in vehicle miles per day per square mile of the downtown part of the same city, and there is reason to believe that the percentage increase in vehicle miles per day per square mile will be the same for each square mile of the area of interest, then this is a satisfactory way to use the growth factor. If the value is simply the projected increase in vehicle population or vehicle miles per day in the total metropolitan area then there is no reason for believing that growth distribution will be uniformly distributed, and there are reasonable grounds for assuming that the model would give misleading results.

If the air quality standard to be met is a short-term standard, which is most severely tested by meteorological situations which mix the pollutants thoroughly in a finite volume of air (as for example under inversion conditions in a completely enclosed valley) then the growth factor as shown in the simple model is probably satisfactory if the boundaries of the area considered are the same as the boundaries of the area whose emissions are trapped in this body of air. If, on the other hand, the standard to be used is an annual average standard, or some other standard which does not represent this "thorough mixing of all emissions in a fixed, finite volume of air" then the growth factor used in simple rollback should be very conservative, leading to much more restrictive standards than would be needed for a model which took into account growth in emissions per unit area in the areas of greatest interest, rather than total emissions in some arbitrarily defined metropolitan area.

The growth factor as defined in Eqs. (12) and (13) is simply the ratio of the population of emitters (residences or cars or factories etc.) at the time when the standard is to be met, divided by the population of emitters at the time c_{max} was measured. There has been some discussion over whether this future population should be obtained by linear or logarithmic extrapolation of existing population trends. This is really a question outside of the basic rollback model. It asks for the value of the population on the appropriate date; it is the responsibility of the demographers, planners, etc. to determine the most reliable way of estimating that value.

4. Simple rollback is applicable for short-lived pollutants (those whose "half-life" in the atmosphere is comparable to their travel time across a metropolitan area at the wind velocity of interest) only if the spatial distribution of emissions is unchanged. This means that any growth by "expanding into the suburbs" cannot be modeled for a short-lived pollutant by simple rollback. Short-lived pollutants can be modeled by simple rollback for the "complete mixing within a fixed finite volume of air" situation only if there is instantaneous horizontal mixing of pollutants over the entire area being modeled.

5. Simple rollback is applicable to the problem of determining the effect on air quality of a change in emission rate of one emitter or one class of emitters, without equal percentage changes in the emission rates of the other classes of emitters, only if one of the following three situations exist: either (1) The class we are considering is by far the largest contributor of the pollutant in question, so that we can ignore the effects of the others, or ignore the inaccuracy of making the assumption that their contribution to the concentration at the worst point has the same factor of proportionality as the contribution of the source or groups of sources we are considering, or (2) The class we are considering has the same temporal, spatial and vertical distribution of emissions as the average of all the other emissions in the area being modeled, so that a change in its emission rate has the same effect on emission distribution in time and space as a properly-scaled reduction in all emissions rates would have, or (3) The standard for this pollutant is a short-term standard which is most severely tested in periods of excellent mixing within

a limited unchanging air volume, as might occur in a well-mixed layer under an inversion in a completely closed valley with no exchange of air with the surrounding area. Then we can ignore the difference between the excellent mixing described here and the perfect mixing which rollback would require.

If none of these three conditions can be shown or reasonably assumed to exist, then the application of simple rollback or proportional modeling to the question of the impact of changes in the emission of one class of emitters on ambient air quality is totally without theoretical or experimental foundation.

6. Simple rollback assumes that the meteorological conditions which existed when c_{max} and e were measured are those which will exist on the date when the standards are to be met. Climate does change without human intervention, and growth of cities and growth of energy release does influence climate, so this is not necessarily a sound assumption. The more advanced models (2-5) generally also make this assumption, so they have this limitation in common with rollback. However, with them one can compute the effects of changes in meteorology, and thus estimate the sensitivity of the prediction to such changes; with rollback such a sensitivity test does not appear possible.

MORE ADVANCED MODELING SCHEMES

The previously listed limitations of simple rollback have led air pollution workers to try to develop modeling schemes which do not have these limitations. Most of these improved models begin with Eq. (15)

$$c_i = b + \Sigma k_{ij} e_j \tag{15}$$

where c_i is the concentration at receptor no i,

e_j is the emission rate for emitter j

and k_{ij} is the source-receptor-interaction for emitter j and receptor i.* One customarily uses a "source inventory" to find the individual values of the e_j (either source-by-source for large "point sources" like power plants, or in aggregates called "area sources" for autos and home heaters and incinerators). The values of k_{ij} are based on meteorological calculations. These meteorological calculations generally fall into two categories, each of which seems applicable under some meteorological circumstances. These are: (1) moving box models, in which pollutants are assumed to be totally mixed within certain vertically-limited air parcels which travel with the general wind velocity, and may exchange matter with surrounding boxes as they move, and (2) gaussian plume models which assume that the pollutants are dispersed according to "gaussian plume" formulae.

Such models may be instantaneous, solving for the concentration at a given point at a given time, taking into account only the current and recent past meteorology, or long term, sampling the various meteorological conditions and assigning frequencies to each, and then computing the concentrations for each meteorological condition, multiplying this by the frequency and summing to compute the long-term average concentration.

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*The k_{ij} shown here is normally shown in the air pollution literature as (x_i/Q_j). The simple form here is used for ease of typing and clarity of presentation.

These more advanced models make more detailed predictions than rollback, which makes it possible to test their assumptions against experimental data. They allow one to predict the spatial distribution of various concentrations of pollutants on a given day, or for some long time period, which is not possible by simple rollback. These computed distributions can be compared with measured air quality, and the models modified to obtain superior agreement. In addition they can make short-term predictions for specific meteorological conditions, which can be compared with observed values. Because these more advanced models have this testing potential, they have been widely studied and tested. As a result we have a much greater degree of experimental confirmation of them, and much more confidence in their predictions than we have for simple rollback.

The relationship between these more advanced models and simple rollback may be clarified if we consider the two circumstances in which the more advanced models give practically the same answers as the simple rollback equation. These are:

1. The situation in which all polluters in the region make proportional reductions, and the proportionate spatial, temporal and vertical distribution of these pollutants is unchanged. In that case we may write

$$e_j = (e_j)_{\text{original}} \cdot \text{proportionality factor} \qquad (16)$$

Substituting this into Eq. (15) we find

$$c_i = b + \Sigma[k_{ij}\ (e_j)_{\text{original}} \cdot \text{proportionality factor}] \qquad (17)$$

If and only if this proportionality factor is the same for each of the j emitters (or classes of emitters), then we can factor it out of the summation sign to get

$$c_i = b + \text{prop. factor} \cdot \Sigma[k_{ij}\ (e_j)_{\text{original}}] \tag{18}$$

But if, as assumed, there is no change in the relative spatial and temporal distribution of emissions then the summation term is a constant, because none of the factors which influence the k_{ij} have changed and the $(e_j)_{\text{original}}$ are constants. Thus we have

$$c_i = b + \text{prop. factor} \cdot \text{a constant} \tag{19}$$

which is merely another way of writing Eq. (1). Thus, in this case both the advanced models and simple rollback indicate that at any point (not only the most polluted point) the observed concentration for the appropriate time period is a linear function of the proportionality factor applied to the baseline emission rate.

The other situation in which rollback and more advanced models coincide is the situation in whch the standard of interest is a short-term one which is most severely tested during a period in which we have perfect and instantaneous mixing of pollutants within a finite air volume. In this complete-mixing situation all the values of k_{ij} are the same, so that Eq. (15) becomes

$$c_i = b + k_{ij}\ \Sigma e_j \tag{20}$$

but

$$\Sigma e_j = e$$

so that this also reduces to Eq. (1), with the further proviso that the concentration is the same at every point in the air mass of interest. For this complete-mixing situation both rollback and the more advanced models must give the same results.

EXTENSIONS OF SIMPLE ROLLBACK

As described above, more complicated modeling procedures are theoretically sounder and better experimentally verified than simple rollback. Thus, one might well ask why bother with improved versions of rollback? The justifications for so doing are:

1. The required input data for rollback is much less than the required input data for the more complicated models.

2. Only a few of the best-equipped air-pollution groups in the country are capable of performing the calculations for the more advanced models, while anyone with a pencil and a slide rule can do rollback calculations.

3. Although the more advanced models have been experimentally tested for SO_2 and total suspended particulates, they have not been developed and adequately tested for photochemical oxidants, NO_2 or hydrocarbons. Similarly, the area source emission structure used in the models for SO_2 and TSP is not necessarily applicable without further work to emissions from motor vehicles. These should not be drawbacks to using the advanced models without this adequate verification, if one intends to use instead the totally unverified rollback model in their place; but in many minds it apparently is.

For all of these reasons, there appears to be a need for improved and/or extended rollback models, to use until we have all the necessary data to use the more advanced models, and we have adequate verification of their predictive ability, and there exists widespread capability and/or willingness to use them.

ROLLBACK WITH VARIOUS EMISSION CATEGORIES

The first obvious extension of rollback can be made if we wish to study the effects of various classes or groups of emitters of a single pollutant. We can treat this problem by returning to Eq. (15), and assuming that the k_{ij} for the various classes are the same. As discussed previously this has no experimental basis and is only theoretically defensible if all the classes have the same spatial, temporal and vertical distribution or if we have a totally-mixed-limited-air-mass situation. If these assumptions can be made then

$$c_i = b + k_{ij}\ \Sigma e_j \tag{22}$$

We may determine this value of k_{ij} from the maximum value of c measured in the region under study during some baseline period, and the known emissions during that period. We find

$$k_{ij} = (c_{\text{max-baseline}} - b)/\Sigma(e_j)_{\text{baseline}} \tag{23}$$

Substituting this value in Eq. (22) we find

$$c_{\text{max}} = b + (c_{\text{max-baseline}} - b)\ \Sigma e_j/\Sigma(e_j)_{\text{baseline}} \tag{24}$$

Eq. (24) can be arranged in several useful forms. If we write

$$e_j = (e_j)_{\text{base}} \cdot gf_j \cdot cf_j \tag{25}$$

where ef and gf have the same meanings as before, and define fractional contribution, fr, as

$$(fr_j)_{\text{base}} \equiv (e_j)_{\text{base}}\ /\ \Sigma(e_j)_{\text{base}} \tag{26}$$

then Eq. (24) can be rewritten as

$$c_{\text{max}} = b + (c_{\text{max-base}} - b)\ \Sigma\ [(fr_j)_{\text{base}}\ gf_j ef_j] \tag{27}$$

Eq. (27) may be used for predicting maximum concentration given expected growth and emission factors.

If c_{max} is replaced by std, then the required reduction of any one of the gf_j or ef_j terms may be found given values for the others. For ef_1,

$$ef_1 = (1-{}^{R}1/100) = \frac{1}{(fr_1)_{\text{base}} gf_1}\left[\frac{(\text{std}-b)}{(c_{\text{max-base}} - b)} - \sum_{2}^{j}[(fr_j)_{\text{base}} gf_j ef_j]\right] \tag{28}$$

Another useful form of this equation is

$$\frac{(std - b)}{(c_{max\text{-}base} - b)} \geq \Sigma\left[(fr_j)_{base} gf_j ef_j\right] \qquad (29)$$

which may be used for control strategy analysis and synthesis. The inequality has been introduced to indicate that concentrations less than std are acceptable but greater concentrations are not. Note that the left side of the inequality is determined by initial conditions while the right side contains all the terms amenable to control. Various control strategies may be explored by varying the gf and ef terms and observing whether the inequality is satisfied.

SECOND NUMERICAL EXAMPLE

To apply Eqs. 27-29 we need additional data. In particular, we need a logical (and available) disaggregation of emissions, and the expected emission factors and growth factors for each emission category. These data for our hypothetical example are from Table 1:

Category	LDV	OMS	HI	OI	A
j	1	2	3	4	5
fr_j	.45	.05	.20	.15	.15
gf_j	1.28	1.34	1.40	1.22	1.28
ef_j	.4	.8	.5	.7	1.0

and $c_{max\text{-}base}$, std, and b are the same as in the previous example. The category abbreviations stand for light duty vehicles, other mobile sources, heavy industry (including power plants), other industry, and area sources.

As a first step, we may apply the data to Eq. 27 to see what concentration results from the expected growth and control.

$$c_{max} = 10 + (200-10)[(.45)(1.28)(.4)+(.05)(1.34)(.8)$$
$$+(.20)(1.40)(.5)+(.15)(1.22)(.7)+(.15)(1.28)(1.0)]$$

$$c_{max} = 10 + (190)(.230 + .053 + .140 + .128 + .192)$$

$$c_{max} = 10 + (190)(.743) = 151\ \mu g/m^3$$

The expected control is clearly inadequate to meet the standard. In order to explore the possibilities for additional control, we use Eq. 29.

$$\frac{100-10}{200-10} = .474 \overset{?}{\geq} \overset{\text{LDV}}{.230} + \overset{\text{OMS}}{.053} + \overset{\text{HI}}{.140} + \overset{\text{OI}}{.128} + \overset{\text{A}}{.192} = \overset{\Sigma}{.743}$$

The abbreviations have been added over the category contributions to aid identification. Although LDV is the most prominent contributor, it can be seen by inspection that the inequality cannot be satisfied by further control of LDV alone. Let's assume that means can be found to reduce the emission factors for OMS, OI, and A to .4, .5, and .7 respectively and we wish to know what ef_1 (LDV) must be to achieve the standard. We use Eq. 28.

$$ef_1 = (1-R_1/100) = \frac{1}{(.45)(1.28)}[.474-(.05)(1.34)(.4)-(.20)(1.40)(.5)$$
$$-(.15)(1.22)(.5)-(.15)(1.28)(.7)] = .140$$

and $R_1 = 86\%$.

Thus, even with the further reduction in emissions from OMS, OI, and A, LDV emissions must be reduced by 86%, as opposed to the expected 60%, to meet the standard using the simple rollback formula.

Other combinations of emission and/or growth control could be explored using Eq. 27-29 but to continue the example seems pointless since, as previously discussed, this extention of rollback only has theoretical basis for the case of equal spatial and temporal distribution of emissions or perfect mixing, neither of which seems applicable to the general case of "pollutant x" in "hypothetical city."

A SEMI-DIFFUSION FORM OF ROLLBACK

What is proposed now is to take a few steps in the direction of diffusion modeling. This will require additional complexity, more data, and several more assumptions. The complexity will remain in the domain of hand calculation, the data is generally available or soon will be, and the assumptions, though rather crude, are much better than those that have been required to support the models considered thus far.

The following development is rather lengthy and mathematical. Our objectives will be previewed here so that you will know where the development is leading. Three successively more complex models will be presented, all of which use some Gaussian diffusion concepts. The first considers the effect of emission height only. The second includes emitter-receptor (ij) distance. The third includes wind direction as well. The first requires no additional emission categories, but does require emission height by category and some meteorological data. The second and third models require the subdivision of emissions by location as well as by type, and the third model requires more meteorological data.

Each of the models is based on a determination of a value of k_{ij} unique to each emission source division.

Recall Eq. (15).

$$c_i = b + \Sigma\, k_{ij}e_j \qquad (15)$$

We may also write

$$(c_i)_{\text{max-base}} = b + \Sigma[k_{ij}(e_j)_{\text{base}}] \qquad (30)$$

When Eq. (15) is divided by Eq. (30) and rearranged, we get

$$\frac{(c_i-b)}{(c_{\text{max-base}}-b)} = \frac{\Sigma[k_{ij}e_j]}{\Sigma[k_{ij}(e_j)_{\text{base}}]} \qquad (31)$$

If we substitute

$$e_j = (e_j)_{base} \cdot gf_j \cdot ef_j \qquad (25)$$

into Eq. (31), we get

$$\frac{(c_i - b)}{(c_{max-base} - b)} = \frac{\Sigma[k_{ij}(e_j)_{base} \cdot gf_j \cdot ef_j]}{\Sigma[k_{ij}(e_j)_{base}]} \qquad (32)$$

We now define the weighted fractional emission contribution for each category as

$$(wf_j)_{base} \equiv \frac{k_{ij}(e_j)_{base}}{\Sigma k_{ij}(e_j)_{base}} \qquad (33)$$

and substitute this into Eq. (32) to yield

$$\frac{(c_i - b)}{(c_{max-base} - b)} = \Sigma\left[(wf_j)_{base} \cdot gf_j \cdot ef_j\right] \qquad (34)$$

Eq. (34) is the general model from which all other models are derived through a series of assumptions. The assumption needed for it to be a rollback model is: If c_i is the standard and if the ef_j and gf_j are sufficient to balance the equation, then the standard will be attained throughout the region as well as the point of maximum concentration. This assumption is quite probable, but is by no means certain and should not be neglected or forgotten.

If all k_{ij} are equal, then (wf_j) becomes (fr_j) in Eq. (26). If in addition there is only one category, j, then we have simple rollback. In the general case, the k_{ij} are not equal and the wf_j will be different from fr_j due to differences in emission source height and location.

Before we leave Eq. (33) and (34) for a while in search of approaches to k_{ij}, note that k_{ij} appears in each term in both the numerator and denominator of Eq. (33). The absolute value of k_{ij} is, therefore, unimportant for our purposes; we only need values that are proportional to k_{ij}. This fact will allow several shortcuts in the following development.

Consider the formulation of k_{ij} which appears in the most widely used meteorological diffusion equation, the Gaussian.

$$k_{ij} = (\chi_i/Q_j) = \frac{1}{\pi\sigma_y\sigma_z u} \exp\left(\frac{-H^2}{2\sigma_z^2}\right) \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \qquad (35)$$

where u is the wind velocity

H is stack height plus plume rise

y is the receptor distance normal to the plume center line and

σ_y and σ_z are the horizontal and vertical dispersion coefficients.

The dispersion coefficients vary with meteorological conditions and with the down wind source-receptor distance.

Values of of $\chi u/Q$ have been plotted for y=0 (directly under the plume centerline) by Turner[6] for six atmospheric stability classes, several values of H, and several inversion heights, L. These curves are reproduced for C and E stability in Figures 3 and 4.

In order to use these curves to generate k_{ij} values for source categories, we must make simplifying assumptions for u and σ_y. The first assumption is that the wind speed, u, is the same for all source categories at any given time. This is a rather poor assumption as it is known that wind speed increases with height; however, the same assumption is made in the advanced diffusion models. The result of this assumption is that elevated sources will be given more weight than they should be. The second assumption is that σ_y is proportional to x, the radial distance from the source along the plume centerline. Actually the best current observations indicate that σ_y is proportional to $x^{.91}$ for all stability classes (from Figure 3-2, ref. 6). The result of this assumption is to weight distant sources somewhat more heavily than is their due.

Now consider a category of sources--say heavy industry. The individual sources making up the category may be distributed all over the region in question in which case it may be impossible to differentiate the location of this category from the others. The total emission height, however, is a characteristic of source types. The stack height plus plume rise for power plants and heavy industry is clearly greater than that for light industry, commercial and apartment buildings, which, in turn, is greater than the emission height of mobile sources. Our first effort, then, will be to develop k_{ij} factors based on emission height and independent of location. To do this, we need a measure of the relative impact of a source on the total region as the source height is varied.

It follows from our assumption that $\sigma_y \propto x$ that emissions from a point source will effect a wedge-shaped area of the region for any one wind direction. This area actually has fuzzy edges. The cross-wind concentration follows the normal distribution with the mode at the plume centerline and standard deviation σ_y. The two lines bounding the wedge are actually the loci of the cross-wind concentration standard deviation points as x varies. Since $\sigma_y \propto x$, any characteristic width of the cross-wind distribution we may choose will also be proportional to x. We now define an element of this effected area as shown in Figure 5. The area of the element is proportional to xdx. The k_{ij} for the element is given by the appropriate $(\chi u/Q)$ curve. The total source contribution to ground-level concentration in the region is proportional to the integral of each elemental k_{ij}. Thus

$$k_j \propto \int_0^d (\chi u/Q)_x \, xdx \tag{36}$$

where the i subscript has been dropped to indicate that the k_j thus derived is independent of receptor location. The limit of integration, d, will depend on the size of the region in question. It should correspond to the radius from the maximum concentration point to the boundary of significant emission density. If the effect of distant sources is neglected by this truncation, this is compensated by the assumption that $\sigma_y \propto x$.

The integration indicated in Eq. (36) has been carried out for Class C and E stabilities in Figures 6 through 9 as a function of d and H. Figures 6 and 7 show values of the product $(\chi u/Q)(x)$, and figures 8 and 9 show the integral of this product out to d. Please note that the ceiling height, L, has been assumed infinite for these calculations. This is not the correct estimate for many areas and is most probably incorrect for high, short-term concentrations. Figures 6-11 should only be applied in areas and for time periods when C or E stability and infinite mixing height are the best estimates of average conditions.

To use these figures, or figures like these, each source category must be assigned a characteristic H value. It is accepted practice among meteorologists to use a minimum H of 10 meters. Since the minimum emission height will give the greatest k_j factor, and since we are not interested in the absolute values of k_j, we may make the use of Figures 8 and 9 more convenient by dividing each k_j value by the corresponding k_j for H-10 meters thus producing a weighting factor for emission height ranging from 0 to 1.0. The resulting weighting factor will be named h_j. Values of h_j are plotted for C and E stability in Figures 10 and 11. The appropriate h_j factors may be entered in place of k_{ij} in Eq. (33) thus

$$(wf_j)_{base} = \frac{h_j(e_j)_{base}}{\Sigma[h_j(e_j)_{base}]} = \frac{h_j(fr_j)_{base}}{\Sigma[h_j(fr_j)_{base}]} \tag{37}$$

THIRD NUMERICAL EXAMPLE

In order to apply the h_j factors we must estimate the characteristic H for each source category, the limit of significant emission density for "hypothetical city," and the appropriate atmospheric stability class. All three of these estimates involve "engineering judgment" rather than precise measurement. Nevertheless, such judgment is considerably more accurate than the assumption that all emission heights or city sizes are the same.

The required estimates, from Table 1, are

Stability Class - E, no ceiling

Integration limit - d=20 km

Category	LDV	OMS	HI	OI	A
H_j (meters)	10	10	100	30	20
h_j (From Figure 11)	1.0	1.0	0.3	.76	.87

Stability class E has been selected because the standard for pollutant x is assumed to be a short-term standard, say 8 hours. It has been observed that the stability is usually class E with a ceiling over 300 meters during the 8-hour periods of high concentration in "hypothetical city." If the standard had been an annual average, then class C stability would be more appropriate.

These data are combined below with that from the previous example.

Values and Calculations for Example 3

	LDV	OMS	HI	OI	A	Σ
j	1	2	3	4	5	-
$(fr_j)_{base}$	.45	.05	.20	.15	.15	1.0
h_j	1.0	1.0	.3	.76	.87	-
$h_j(fr_j)_{base}$	.45	.05	.06	.11	.13	.80
$(wf_j)_{base}$ (Eq. 37)	.562	.063	.075	.137	.163	1.0
gf_j	1.28	1.34	1.40	1.22	1.28	-
ef_j	.4	.8	.5	.7	1.0	-
$(wf_j)_{base}gf_jef_j$	.288	.067	.053	.117	.209	.734 (Eq. 34)
Target sum (Eq. 34 and second example)						.474

The maximum concentration given the expected ef_j and gf_j is

$$c_{max} = 10 + (200-10)\ (.734) = 149\ \mu g/m^3$$

which is almost the same as in the previous example. Observe, however, that the category contributions, $(wf_j)_{base}gf_jef_j$, are altered due to the weighting by h_j. Eq. (34) can now be balanced by further reduction of the LDV contribution alone. If $(wf_1)_{base}gf_1ef_1$ is reduced from .288 to .028, Eq. (34) will balance. This requires

$$ef_1 = .028/(.562)(1.28) = .039$$

or $R_1 = 96\%$.

Since a reduction of 96% in LDV emissions in 5 years is rather heroic, let's see what ef_1 would be required if the additional reduction in ef_2, ef_4, and ef_5 mentioned in Example 2 were applied. From Eq. (28)

$$ef_1 = \frac{1}{(.562)(1.28)} [.474-(.063)(1.34)(.4)-(.053)-(.137)(1.22)(.5) -(.163)(1.28)(.7)]$$

$$ef_1 = \frac{1}{.719} (.474-.317) = .218$$

and R_1 is 78%. This is quite a bit different from the 86% found in Example 2.

THE LOCATION FACTOR

A glance at Figures 3 and 4 should convince the reader that source-receptor distance is the most critical factor in determining k_{ij}. If we can disaggregate source categories by location, then we can include consideration of source-receptor distance in the k_{ij} and simultaneously relax the worst assumption we have been carrying thus far; namely that k_{ij} is the same for each source in each emission category.

To see how this might be done, consider how it is done in one of the better known "diffusion models," namely IPP (ref. 3). That model computes the concentration at any point i by

$$c_1 = \sum_{\substack{\text{all}\\ \text{sources}}} \; \sum_{\substack{\text{all wind}\\ \text{directions,}\\ \text{velocities}\\ \text{and stability}\\ \text{classes}}} \left[\begin{pmatrix} \text{frequency} \\ \text{of this} \\ \text{weather} \end{pmatrix} \frac{1}{u} \left(\frac{\chi u}{Q} \right)_{ij} Q_j \right] \tag{38}$$

In the currently used form of IPP there are 480 wind direction, speed and stability classes, to each of which a frequency is assigned from the observed meteorology. Then for each receptor point the concentration is obtained by a sum of the contributions from each source (individually for point sources, or in groups called area sources), with each such contribution being the sum of 480 contributions for different meteorological conditions. (These are normally annual average weather frequencies, and the program is normally used to compute annual averages. From Eq. (38) it is clear that this is not necessary; one can use the same basic approach over any time period).

To make a "rollback" type version of Eq. (38) we proceed as follows. First we assume that the joint wind velocity-wind direction-atmospheric stability frequency distribution is symmetric about the worst polluted point in the city. This makes the summation over meteorological conditions independent of source locations, so that Eq.(38) becomes

$$c_{max} = \begin{bmatrix} \text{an appropriate} \\ \text{meteorological} \\ \text{factor} \end{bmatrix} \sum_{\substack{\text{all}\\ \text{individual}\\ \text{sources}}} \left[\frac{1}{u} \left(\frac{\chi u}{Q} \right) Q_j \right] \tag{39}$$

Next we assume that we can subdivide the area of the city into annular rings about the most polluted point, as shown in Figure 12, and that in each ring, distribution of each category of emitter is uniform over the area. In equation form,

$$\sum_{\substack{\text{All}\\ \text{emitters}}} Q_j = \sum_{\substack{\text{All}\\ \text{classes}}} \sum_{\substack{\text{All}\\ \text{rings}}} \int (e_j/A)_{\substack{\text{That}\\ \text{ring}}} \, dA_{\text{ring}} \qquad (40)$$

where (e_j/A) is the emission density of area element dA.

When we substitute this into Eq. (39) we obtain

$$c_{max} = \begin{bmatrix}\text{an appropriate}\\ \text{meteorological}\\ \text{factor}\end{bmatrix} \sum_{\substack{\text{All}\\ \text{classes}}} \sum_{\substack{\text{All}\\ \text{rings}}} \int \left(\frac{e_j}{A}\right) \frac{1}{u} \left(\frac{Xu}{Q}\right) dA \qquad (41)$$

However, by our assumption that within each ring the emission density for each category is constant, we can take (e_j/A) out of the integral sign. The wind speed may be included in the "appropriate meteorological factor" because it has been assumed to be the same for all parts of the city and to be equally distributed in all directions. We can also note that if we take our area integral as a symmetrical one shown in Figure 12 that the limits of integration for each ring are from x_1 to x_2, and the element of area is

$$dA = 2\pi \; x \; dx \qquad (42)$$

so that

$$c_{max} = \begin{bmatrix}\text{an appropriate}\\ \text{meteorological}\\ \text{factor}\end{bmatrix} 2\pi \sum_{\substack{\text{All}\\ \text{classes}}} \sum_{\substack{\text{All}\\ \text{rings}}} \left[\left(\frac{e_j}{A}\right) \int_{x1}^{x2} \left(\frac{Xu}{Q}\right) x dx\right] \qquad (43)$$

The integral on the right is just the integral we used in the previous version of rollback, and as in all rollback type calculations, the factor in the equation which we have labeled (appropriate meteorological factor) is determined by some form of equation (1), in which we relate present emissions to present worst observed air quality. Thus we can, subject to these assumptions, write:

$$\frac{(c_{\text{max future}} - b)}{(c_{\text{max base}} - b)} = \frac{\left.\sum_{\text{All Classes}} \sum_{\text{All rings}} \left[\frac{(e_j)}{A} \int_{x_1}^{x_2} \left(\frac{\chi u}{Q}\right)_x x\,dx \right]\right|_{\text{Future}}}{\left.\sum_{\text{All Classes}} \sum_{\text{All rings}} \left[\frac{(e_j)}{A} \int_{x_1}^{x_2} \left(\frac{\chi u}{Q}\right)_x x\,dx \right]\right|_{\text{Base}}} \tag{44}$$

When Eq. (44) is compared with Eq. (32), it can be seen that

$$k_{ij} \propto \frac{1}{A_{\text{ring}}} \int_{x1}^{x2} \left(\frac{\chi u}{Q}\right)_x x\,dx \tag{45}$$

The value of the integral is found for each ring-source type in Figure 8 or 9 (or similar curves for the appropriate average stability and ceiling height) by subtracting the value given at x_1 from the value at x_2. The value of A is $\pi(x_2^2 - x_1^2)$ but since only proportionality is needed, the π can be disregarded.

The k_{ij} thus calculated will be named hr_j to signify that both emission height and radial distance from the point of maximum concentration have been considered.

$$hr_j = \frac{1}{(x_2^2 - x_1^2)} \int_{x1}^{x2} \left(\frac{\chi u}{Q}\right)_x x\,dx \tag{46}$$

FOURTH NUMERICAL EXAMPLE

"Hypothetical City" is divided into three annular areas by drawing circular boundaries of radius 2, 10, and 20 kilometers about the point of maximum concentration. We now need the distribution of emission between 15 categories instead of 5. This distribution is taken from Table 1 and is presented in the first column of Table 2. The gf, H, and ef may not be the same for source types in different location zones (e.g., suburbs grow faster than city centers). This is shown in the following three columns of Table 2. The hr_j are found using Eq. (46). For example, for heavy industry in the second ring

$$x_1 = 2 \text{ km}$$

$$x_2 = 10 \text{ km}$$

$$x_2^2 - x_1^2 = 10^2 - 2^2 = 96$$

The integral, for H = 50 m and stability E, is 0.1 at 2 km and 0.7 at 10 km from Figure 9. The value of hr_8 is

$$hr_8 = (0.7 - 0.1)/96 = .00625$$

This and the other similarly calculated hr factors have been multiplied by 100 in the table for convenience. The other indicated calculations are similar to the previous example.

The maximum concentration, given the expected ef_j and gf_j is

$$c_{max} = 10 + (200 - 10)(.662) = 136\ \mu g/m^3$$

which is somewhat less than that obtained with the previous model. For this example, Eq. (34) can easily be balanced by further reduction of LDV emissions. The total $(wf_j)_{base} gf_j ef_j$ for LDV is .106+.117+.028 = .251. This must be reduced to .063 in order to balance Eq. (34) by LDV control.

The required ef_{1-3} is

$$ef_{1-3} = .063/[(.250)(1.0)+(.250)(1.1)+(.041)(1.6)] = \frac{.063}{.589} = .107$$

or R_{1-3} = 89%

If the additional reduction in ef_j for OMS, OI, and A mentioned in the previous example are applied, and the required LDV reduction is calculated, the result is

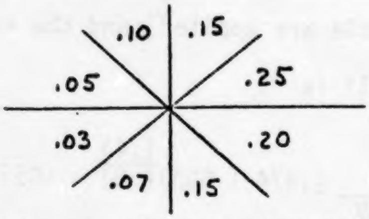
$$ef_{1-3} = \frac{1}{.589}\left[.474-(.033)\frac{(.4)}{(.8)} - .055 - (.101)\frac{(.5)}{(.7)} - (.162)\frac{(.7)}{(1.0)}\right]$$

$$ef_{1-3} = \frac{1}{.583}(.474-.287) = .317$$

and the required R_{1-3} is 68%. Note that our rollback calculations have been markedly effected by the inclusion of location considerations.

THE WIND DIRECTION FACTOR

Our rollback model has grown considerably in complexity and in its need for data with the inclusion of each additional factor. It is still well within range of hand calculation and available data. We will, then, consider one more factor: wind direction. This will require the further subdivision of the region into sectors. Four, 8, or 16 sectors may be used depending on the accuracy desired and data availability. If the standard to be achieved is an annual standard, the annual wind direction distribution must be known. If the standard is for an averaging time less than annual, the wind direction distribution should be obtained for those periods when the standard has been exceeded. A weighting factor is assigned to each sector such that the sum of all sector weighting factors is equal to (1.0) and each sector weight is proportional to the time the wind blows from that sector. The figure below shows one possible set of weights for an 8 sector subdivision.



When the hr_j factor for an emission subdivision is multiplied by the wind direction weighting factor, a k_{ij} factor including height, and location (hl_j) is obtained. This factor is used in the same way as were the h_j and hr_j factors. This addition to our model is relatively simple, but the subdivision of "hypothetical city" into 8 or 16 times 15 categories is tedious so no numerical example will be given.

The inclusion of wind direction in the rollback model requires about an order of magnitude increase in the emission inventory subdivision. As this will create as much more effort in performing the required calculations, it is reasonable to ask under what conditions the increased accuracy is worth the effort. Wind direction will be important if its distribution is decidedly uneven and if the distribution of emission density and/or growth is also unevenly distributed around the annular rings. The latter conditions will almost always be the case, so the decision whether to subdivide by sector depends primarily on the accentricity of the wind direction distribution and, of course, on the availability of the required data.

SUMMARY OF THE ALTERNATIVE MODELS

We may recapitulate by summarizing the results of the several examples:

Example 1: By simple rollback we find that if all sources reduce their emissions by 64%, then the standard will be met. No information can be obtained from this model about the required rollbacks if all sources do not make the same proportional rollback.

Example 2: By rollback with various emission categories, we find that the expected growth and emission factors will reduce c max to only 151 μg/m^3 (the standard is 100 μg/m^3). Attainment of the standard through additional LDV control is impossible. When additional control is applied to OMS, OI, and A, then the standard can be attained if LDV emissions are rolled back 86%. Spatial distribution (three dimensions) of emissions is not considered in this example.

Example 3: By rollback with emission categories and emission height considered, it is found that expected growth and emission reduction will reduce c max to 149 μg/m^3 which is about the same as in Example 2. It is possible to achieve the standard by a rollback of LDV of 96% because LDV contributions are weighted more heavily than others due to their low emission height. When additional controls on OMS, OI, and A are applied, the LDV rollback required drops to 78%.

Example 4: By rollback with emission categories, emission height, and distance from the point of c max considered, we find that the expected c max is 136 μg/m^3. The LDV control needed to achieve standard air quality is 89% without additional control of other source categories, and 68% with the additional control.

If a fifth example had been presented which used a rollback model incorporating wind direction as well as the other factors, and if the wind direction frequency distribution and emission density distribution varied among the several sector subdivisions of "hypothetical city," then we could expect results somewhat different from the previous examples.

CONCLUSIONS AND RECOMMENDATIONS

1. Simple rollback is widely used. However, it has no experimental basis, and its theoretical basis is restricted to very unusual situations; i.e., situations in which we either have perfect atmospheric mixing in the area of interest, or all emitters make the same percentage reduction.

2. It is recommended that we continue to use simple rollback for situations in which we can reasonably assume perfect mixing or equal percentage emission reduction. But if these conditions are not satisfied, then it is recommended that we not use simple rollback, and that calculations based on simple rollback be understood as having no theoretical or experimental basis.

3. It is recommended that Eq. (34) be used as the basic form of rollback. The number of categories, j, and the treatment of wf_j should be the most detailed that the available data will allow. The assumptions leading to the particular form of Eq. (34) used should be explicitly stated and justified.

4. In situations in which we cannot assume perfect mixing, it is recommended that a rollback model with emission type, height, and location considerations be used.

5. In the situations described above we have every reason to believe that full diffusion models (2) will give more reliable predictions of the consequences of changes in emission rates and patterns than any of the rollback models presented herein. Therefore, any result obtained by simple or semidiffusion rollback must be considered a rapid and inexpensive approximation to the more accurate and reliable results which we could obtain with additional time and money by a diffusion modeling effort.

ACKNOWLEDGEMENT

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NOMENCLATURE

A	area	m^2
b	background concentration	$\mu g/m^3$
c	ambient air concentration	$\mu g/m^3$
e	emission rate	gm/sec
ef	emission factor (allowable emission rate per unit of population)/(current emission rate per unit of population)	-
(fr_j)	fraction of total emissions in class j	-
gr	growth rate	%/yr
gf	growth factor (future population)/(current populations) - Population may be households, cars, industries, etc.	-
H	stack height plus plume rise ("effective plume rise")	m
(h_j)	a k factor based on emission height only	$(\mu g/m^3)/(gm/sec)$
(hr_j)	a k factor based on emission height and source receptor distance	"
(hl_j)	a k factor based on emission height, distance, and angular location	"
k	constant of proportionality between c and e see (χ/Q)	"
R	Rollback percentage	-
std	applicable ambient air quality standard	$\mu g/m^3$
u	wind velocity	m/sec
(wf_j)	same as (fr_j) but weighted by a k factor	-
x	downwind distance between source and receptor	m
y	cross-wind distance between source and receptor	m
(χ/Q)	source receptor interaction coefficient, same as k	$(\mu g/m^3)/$ (gm/sec)
σ_y, σ_z	horizontal and vertical dispersion parameters	m

Subscripts

i	receptor
j	source
max	maximum
allowable	allowable to meet standards
baseline base b	corresponding to emission rate from which rollback is to be calculated
x	value at distance x
y	in the crosswind direction
z	vertically

Table 1. Data Used in the Example "Pollutant x," "Hypothetical City"

Parameter	Value (for 8 hrs.)
$c_{max-base}$	200 $\mu g/m^3$
b	10 $\mu g/m^3$
std	100 $\mu g/m^3$
Average growth rate (gr)	5.4%/year
Average growth factor (gf) over 5 years	1.30
Atmospheric Stability Class (for periods above standard)	E (ceiling >300m)
Ring boundary radii	2 km, 10 km, 20 km

	LDV	OMS	HI	OI	A
fr city	.45	.050	.20	.15	.15
Ring 1	.02	.005	.00	.003	.01
Ring 2	.25	.025	.10	.097	.09
Ring 3	.18	.020	.10	.05	.05
gf city	1.28	1.34	1.40	1.22	1.28
Ring 1	1.0	1.1	-	1.1	1.1
Ring 2	1.1	1.3	1.1	1.2	1.2
Ring 3	1.6	1.5	1.7	1.3	1.5
ef city	.4	.8 (.4)	.5	.7 (.5)	1.0 (.7)
Ring 1	.4	.8 (.4)	-	.7 (.5)	1.0 (.7)
Ring 2	.4	.8 (.4)	.7	.7 (.5)	1.0 (.7)
Ring 3	.4	.8 (.4)	.3	.7 (.5)	1.0 (.7)

(ef in parentheses are the limit of further possible reduction in the following 5 years in "Hypothetical City.")

	LDV	OMS	HI	OI	A
H city	10	10	100	30	30
Ring 1	10	10	-	50	50
Ring 2	10	10	50	30	30
Ring 3	10	10	200	30	20

Table 1 (Cont'd)

"Hypothetical City" is just that. The values for all the parameters were selected to conform generally to observed and expected values of the 1970-75 period but do not represent any particular pollutant or place.

Table 2. Data and Calculations for the Third Numerical Example

Source Type	Ring	j	$(fr_j)_b$	gf_j	ef_j	H_j	Hr_j (x100)	$(hr_j)(fr_j)_{base}$	$(wf_j)_b$ Eq.(37)	$(wf_j)_b ef_j gf_j$	
LDV	0-2	1	.02	1.0	.4	10	12.5	.250	.266	.106	
	2-10	2	.25	1.1	.4	10	1.0	.250	.266	.117	.251
	10-20	3	.18	1.6	.4	10	.23	.041	.044	.028	
OMS	0-2	4	.005	1.1	.8	10	12.5	.063	.067	.059	
	2-10	5	.025	1.3	.8	10	1.0	.025	.027	.028	.093
	10-20	6	.02	1.5	.8	10	.23	.005	.005	.006	
HI	0-2	7	0	--	--	--	--	--	--	--	
	2-10	8	.10	1.1	.7	50	.63	.063	.067	.052	
	10-20	9	.10	1.7	.3	200	.05	.005	.005	.003	.055
OI	0-2	10	.003	1.1	.7	50	2.5	.008	.009	.007	
	2-10	11	.097	1.2	.7	30	.94	.091	.097	.081	.101
	10-20	12	.05	1.3	.7	30	.25	.013	.014	.013	
A	0-2	13	.01	1.1	1.0	50	2.5	.025	.027	.030	
	2-10	14	.09	1.2	1.0	30	.94	.025	.091	.109	.162
	10-20	15	.05	1.5	1.0	20	.27	.014	.015	.023	
Σ			1.0					.938	1.0	.662	

Target Sum (from Eq. 34) ——— .474

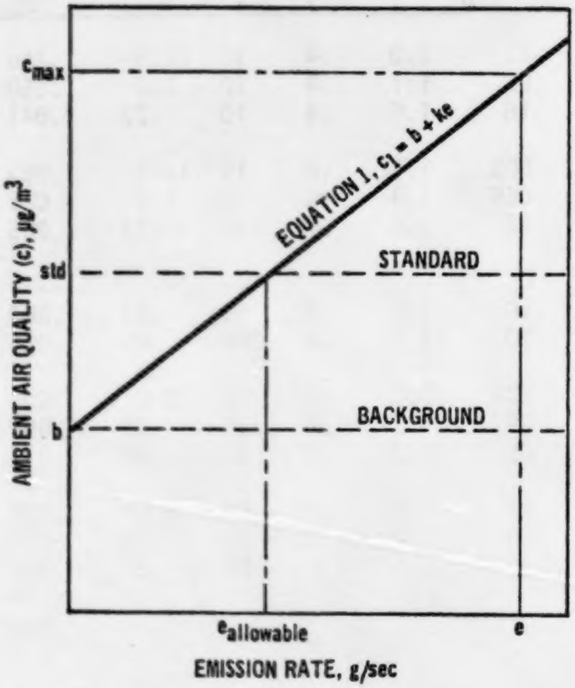


Figure 1. Graphical representation of Equation 1 and the computation of $e_{allowable}$.

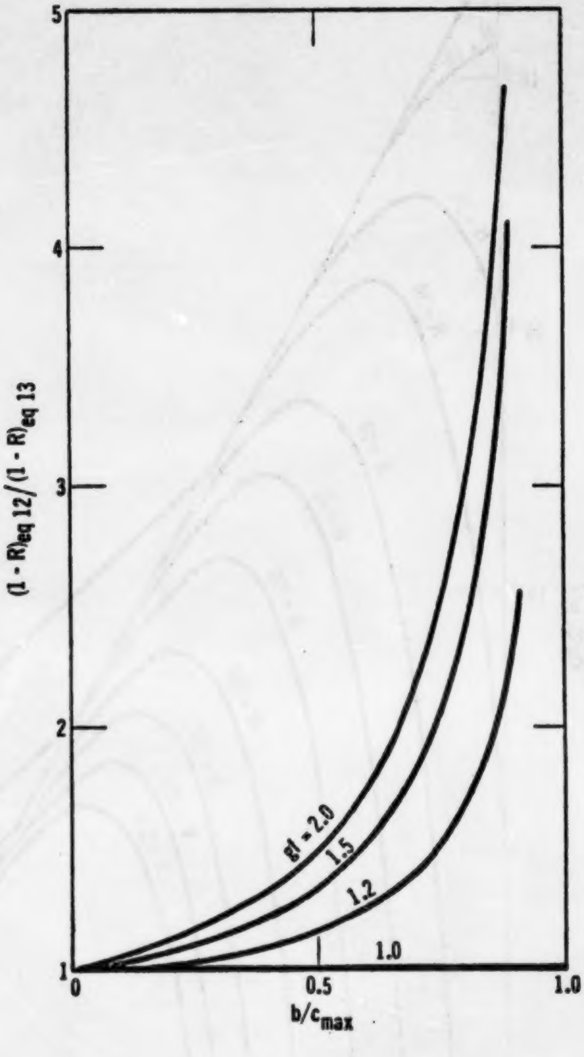


Figure 2. Comparison of complete and simplified forms of simple rollback, for various values of gf and b/c_{max}.

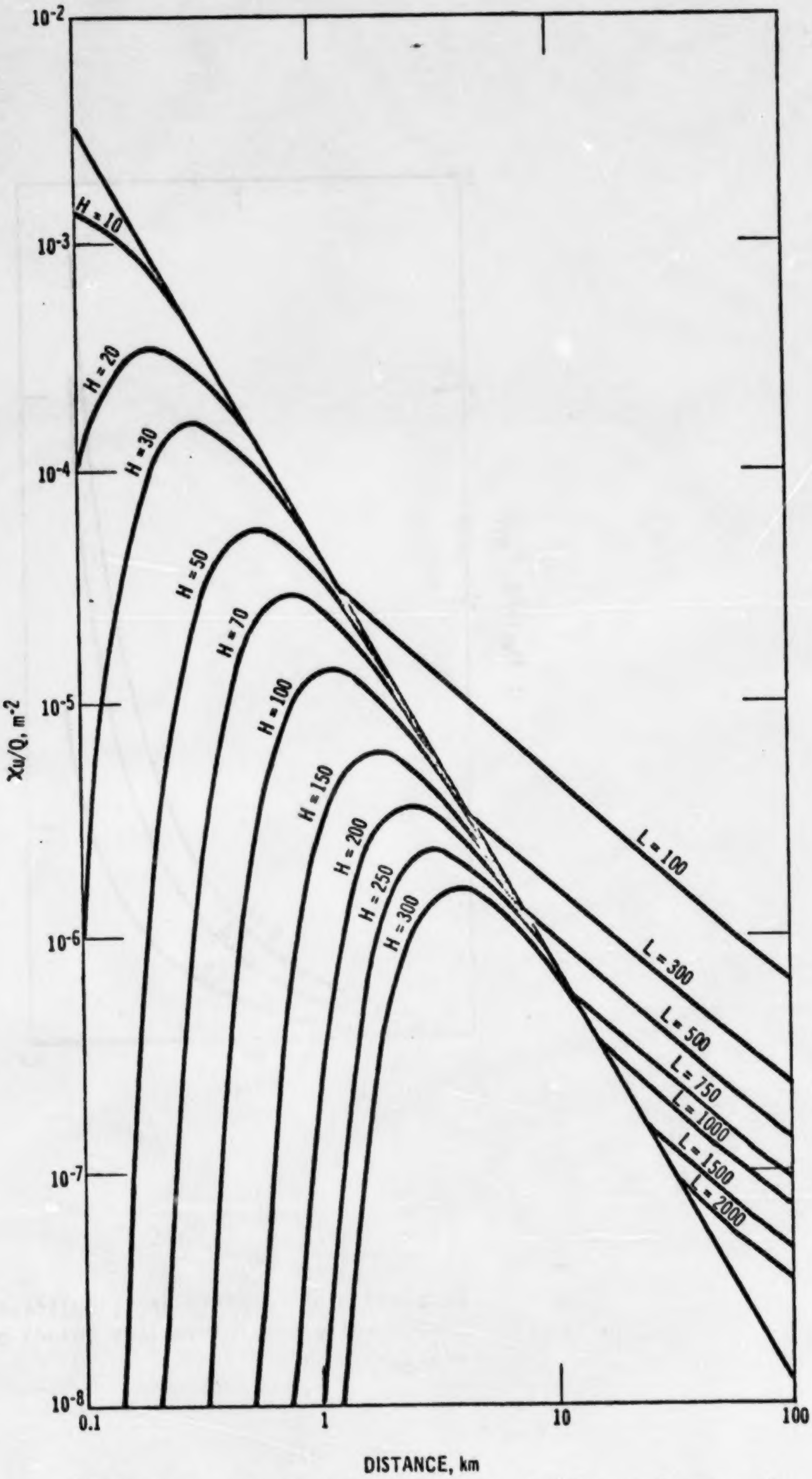


Figure 3. χu/Q for Stability Class C (from reference 6).

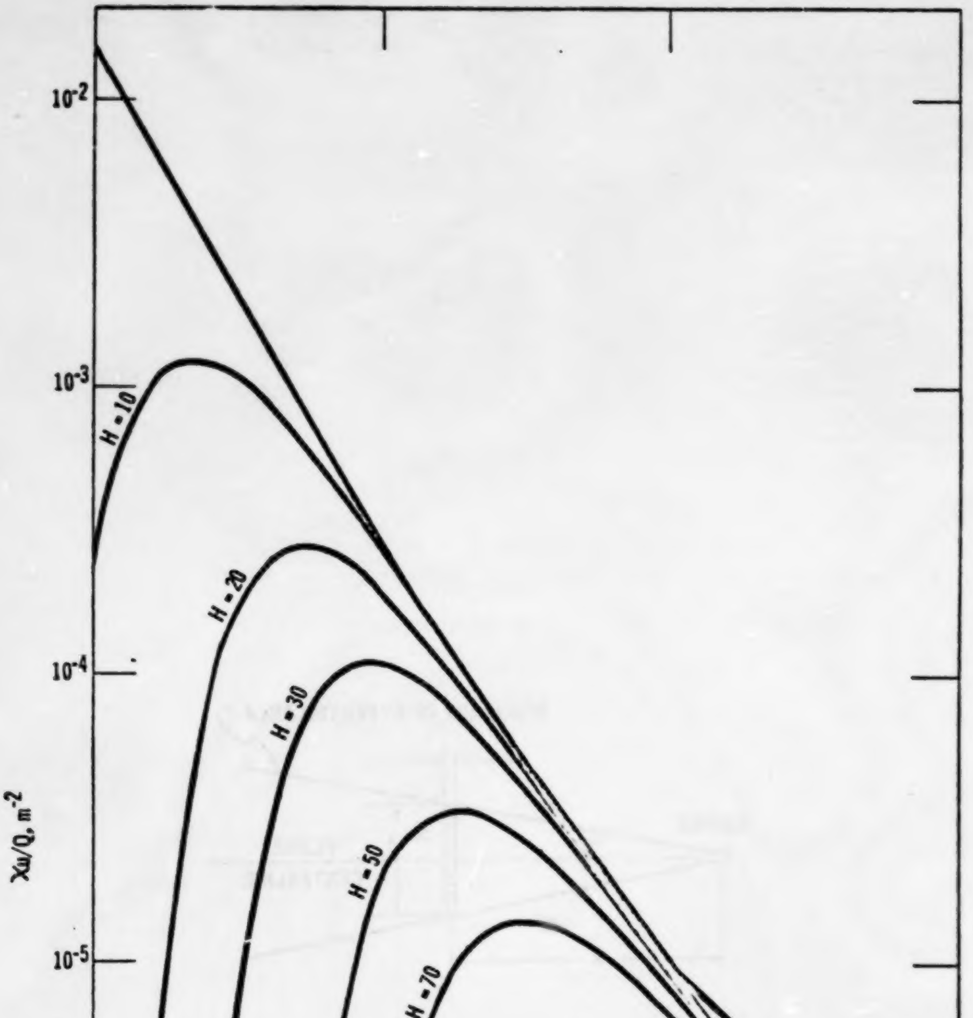
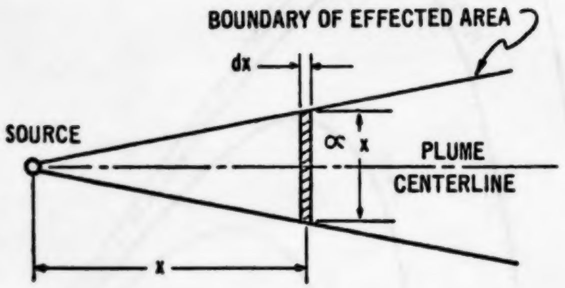


Figure 4. χu/Q for Stability Class E (from reference 6).



$$K_j \propto \int_0^d (\chi u/Q)_x (x) dx$$

Figure 5. Calculation of K_j.

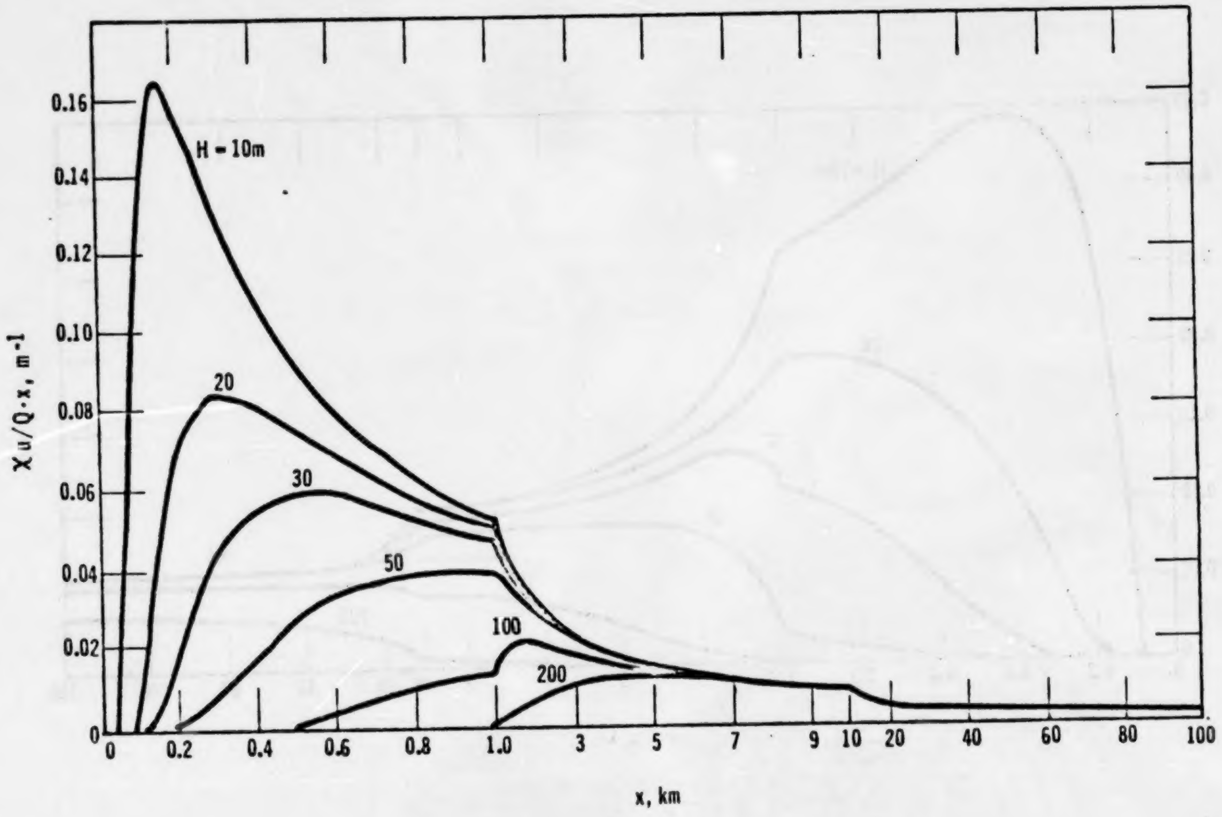


Figure 6. Product of $\chi u/Q$ and x for Stability Class C and ceiling over 2000 m. (Note scale change at x = 1 km and x = 10 km).

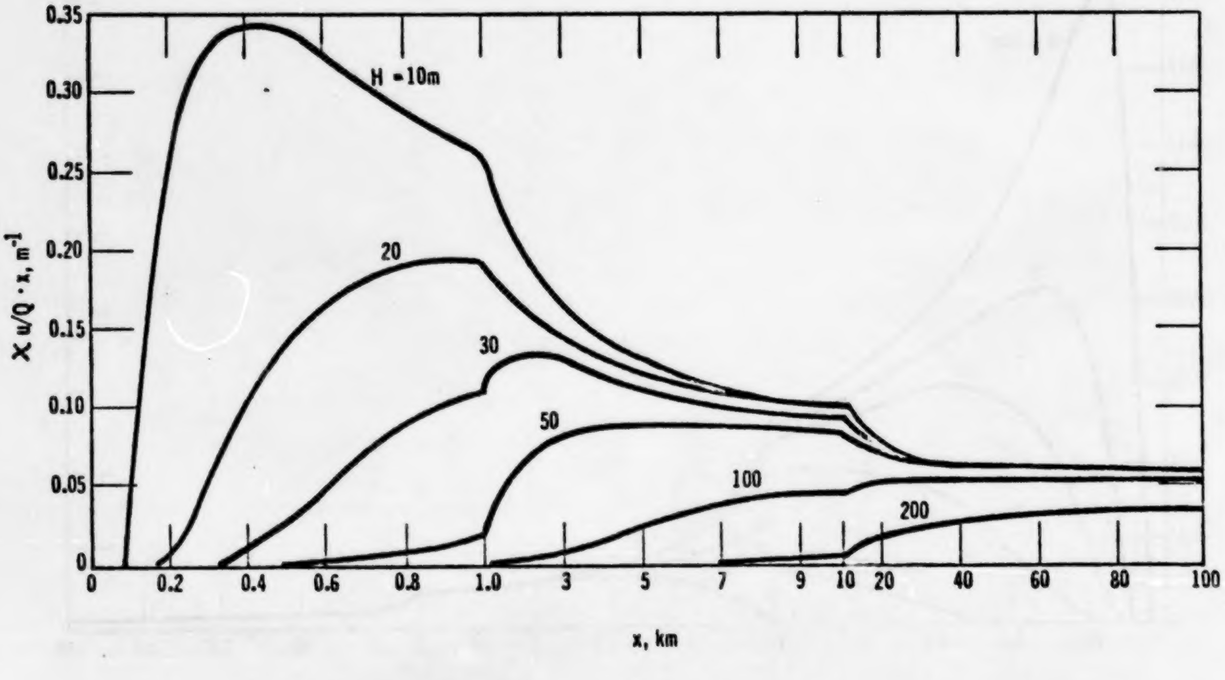


Figure 7. Product of χu/Q and x for Stability Class E and ceiling over 300 m. (Note scale change at x = 1 km and x = 10 km).

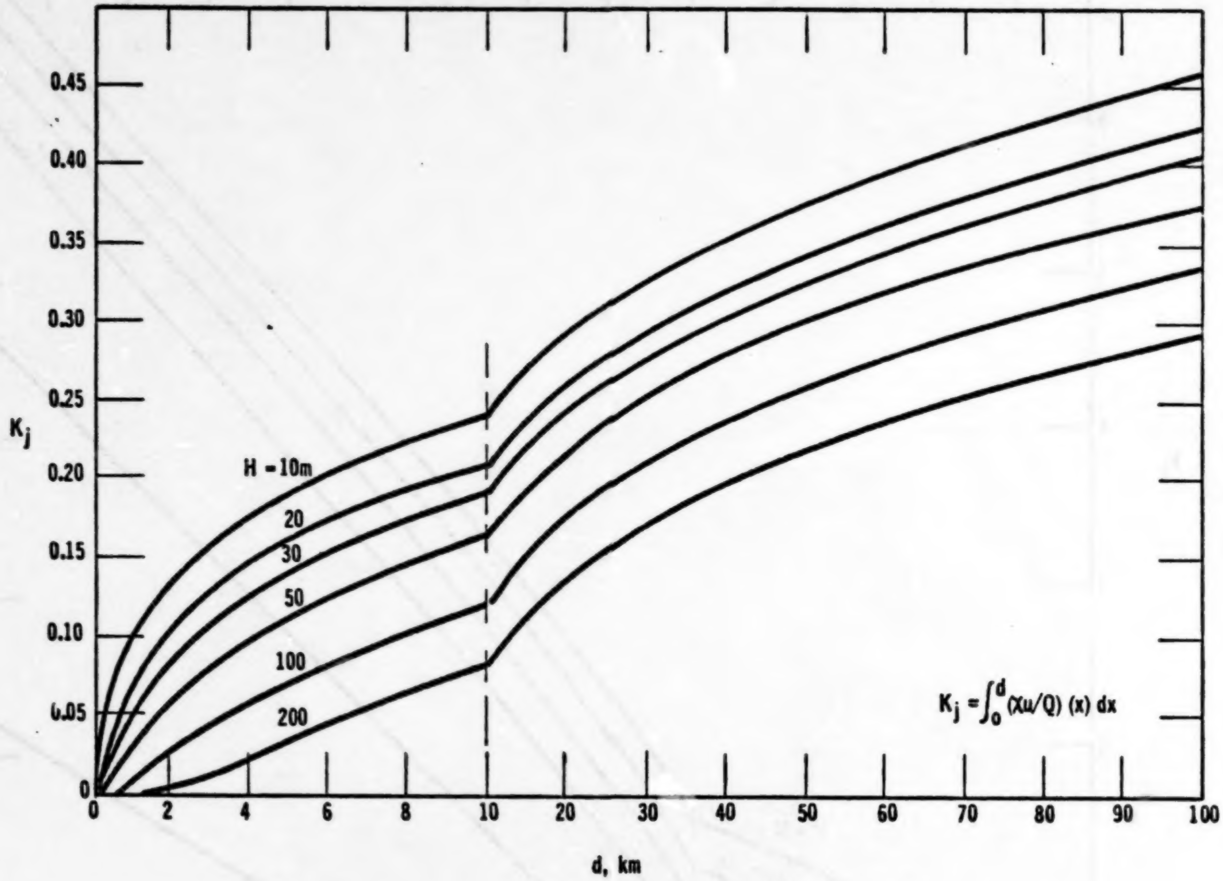


Figure 8. Integral of $(\chi u/Q)(x)$ from zero to x = d for Stability Class C and ceiling over 2000 m. (Note scale change at d = 10 km).

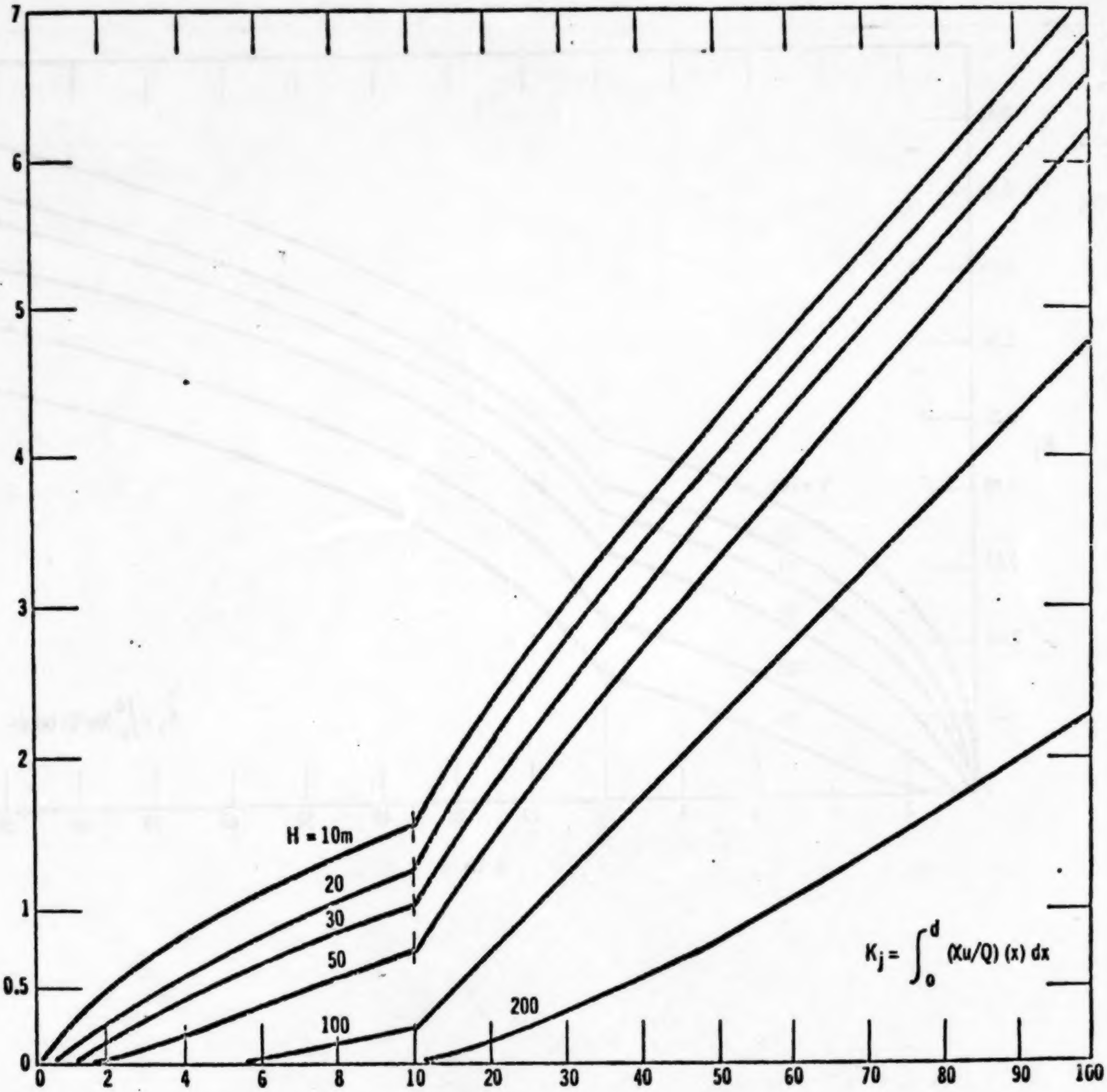


Figure 9. Integral of $(\chi u/Q)(x)$ from zero to $x = d$ for Stability Class E and ceiling over 300 m. (Note scale change at d = 10 km).

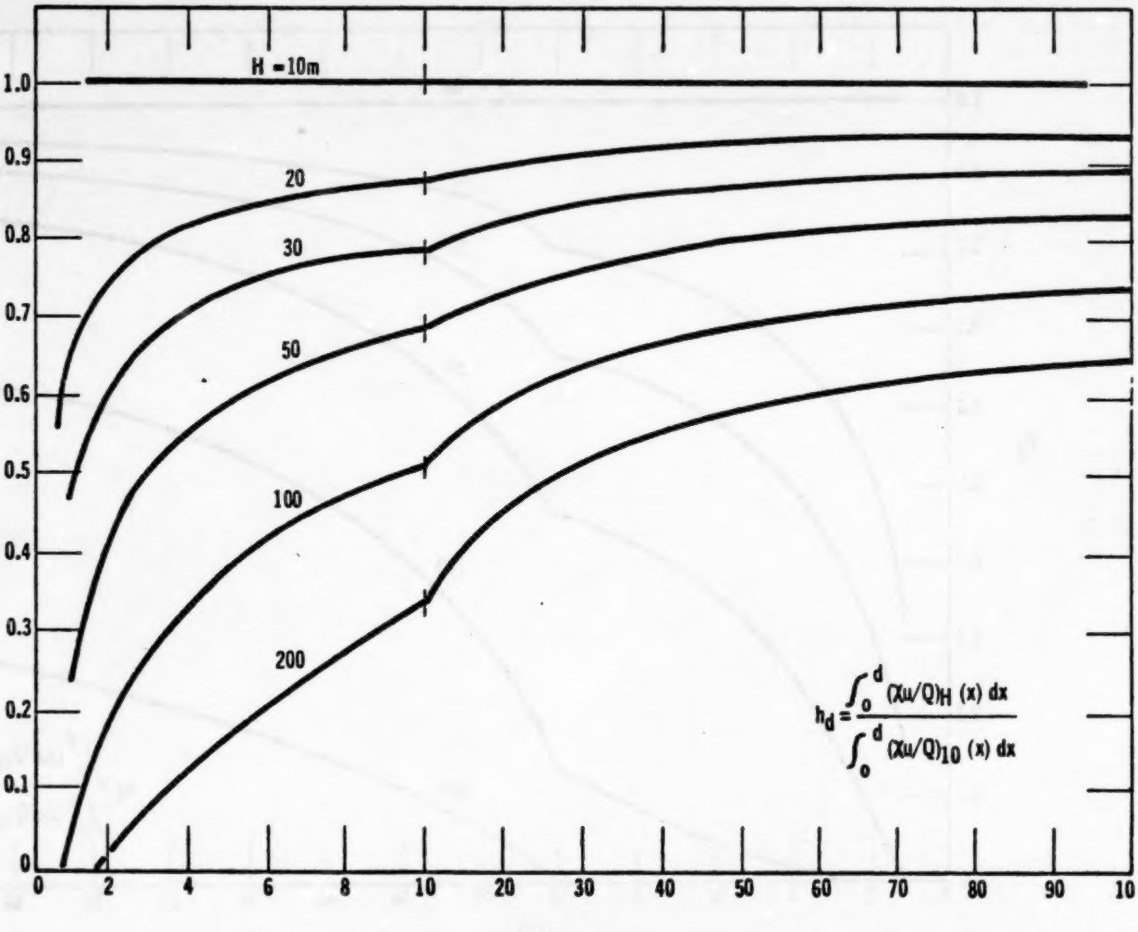


Figure 10. Values of h for Stability Class C and ceiling over 2000 m. (Note scale change at d = 10 km).

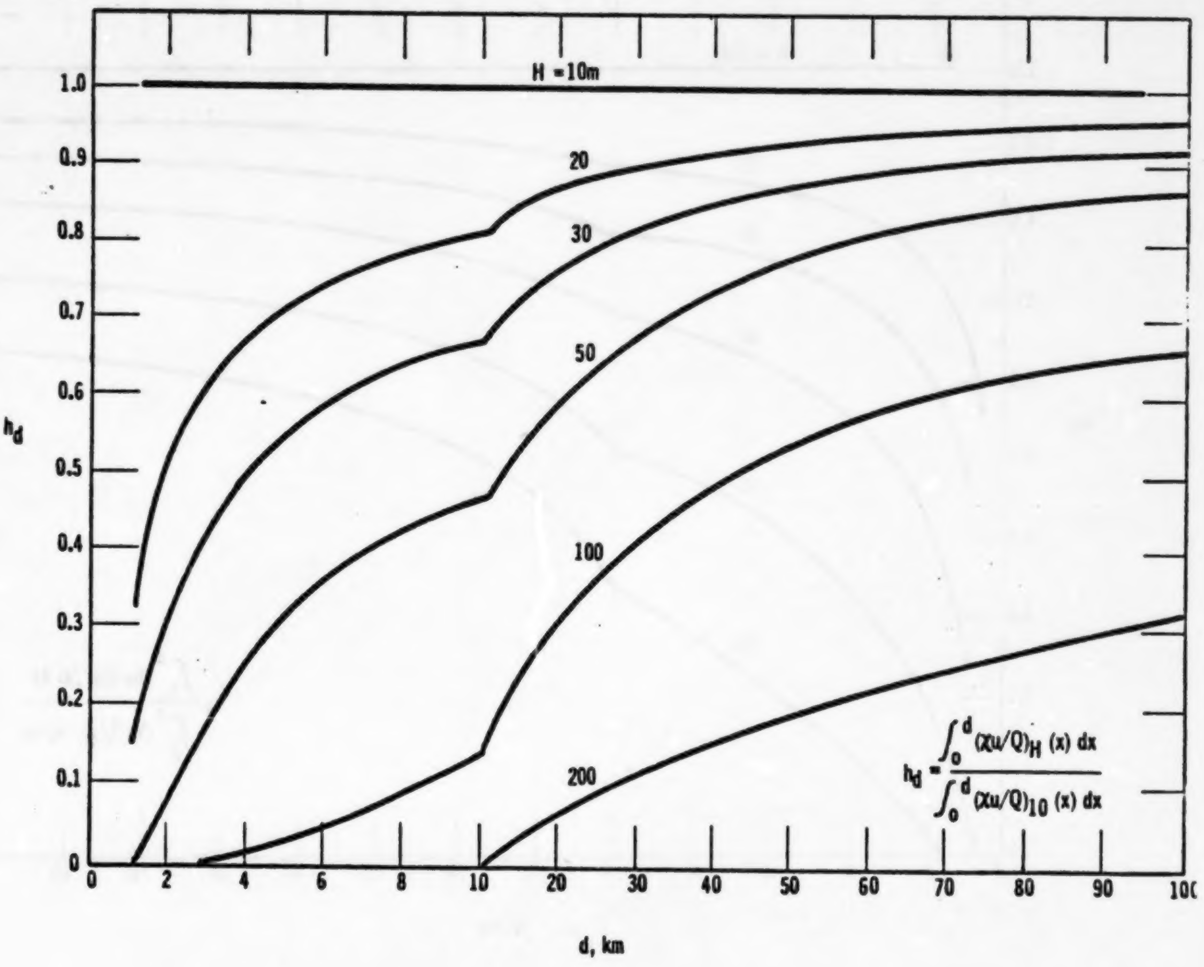
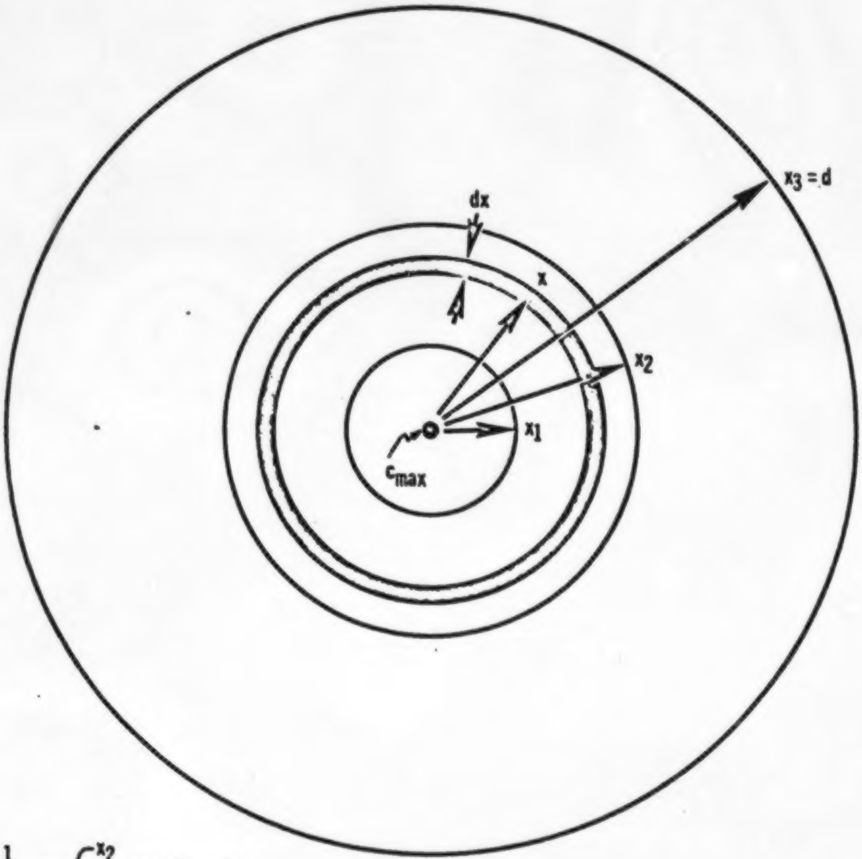


Figure 11. Values of h for Stability Class E and ceiling over 300 m. (Note scale change at d = 10 km).



$$(hr_j) \propto \frac{1}{(x_2{}^2 - x_1{}^2)} \int_{x_1}^{x_2} (\chi u/Q)_x \, (x) \, dx$$

Figure 12. Annular subdivision and calculation of hr_j.